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Earned Value Management in Electrical System Projects

A Case Study

Master's Thesis

Espoo, June 4, 2017

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ABSTRACT OF MASTER'S THESIS

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Competition in business is harsh. The companies are continuously seeking ways to improve the efficiency and customer experience in their business operations. Project business is one very usual way of delivering complex tailor-made systems for B2B customers. Aspects of cost and schedule performance as well as customer satisfaction are important elements in a successfully completed project.

This master's thesis is a case study. The purpose of this thesis is to review earned value management method, find out how it could be implemented in case company's projects and analyse what difficulties and benefits the method would have compared to current way of managing projects. Furthermore, a brief look to topics of projects and project management are discussed.

The implementation is started by identifying a typical project in the case company in terms of planning, scheduling, budgeting and monitoring practices. The key elements of the project are discussed and finally implementation of EVM is focused on one of them due to time limits in this thesis. A concept of EVM was introduced in the engineering process and its advantages and disadvantages are addressed. The results are validated using data from a real ongoing project in the case company. Possible future actions are provided based on the development of identified shortcomings in the EVM concept.

Keywords: Earned value management method, Earned value, Project management, Project, Electrical system projects

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Kilpailu liiketoiminnassa on ankaraa. Yhtiöt etsivät jatkuvasti tapoja parantaa tehokkuutta ja asiakaskokemusta liiketoiminnassaan. Projektiliiketoiminta on yksi erittäin tavallinen tapa tarjota monimutkaisia ”avaimet käteen” -järjestelmiä B2B-asiakkaille. Kustannusten ja aikataulutavoitteiden sekä asiakastyytyväisyyden näkökulmat ovat tärkeä osa onnistuneesti toteutettua projektia.

Tämä diplomityö on tapaustutkimus. Työn tarkoituksena on tarkastella ”ansaittu arvo” -menetelmää ja selvittää, miten se voitaisiin toteuttaa yrityksen projekteissa, sekä analysoida mitä vaikeuksia ja hyötyjä menetelmällä olisi verrattuna nykyiseen projektin hallintaan. Lisäksi keskustellaan lyhyesti projekteista ja projektinhallinnasta yleisellä tasolla.

Työ aloitetaan tunnistamalla miten tyypillisessä tapausyrityksen projektissa käytännössä toteutetaan sen suunnittelu, aikataulutus, budjetointi ja seuranta. Projektin keskeisiä osia käsitellään ja lopulta aikarajoitteiden vuoksi EVM:n toteutus keskittyy yhteen niistä. EVM konsepti otettiin käyttöön projektin suunnitteluprosessissa ja sen edut ja haitat käsiteltiin. Tulokset vahvistetaan käyttäen tietoja todellisesta tapausyrityksen käynnissä olevasta projektista. Mahdollisia kehitysideoida tulevaisuuteen annetaan EVM-konseptista tunnistettujen puutteiden perusteella.

Asiasanat:	Ansaitun arvon menetelmä, Ansaittu arvo, Projektinhallinta, Projekti, Sähkötekniset projektit
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Abbreviations and Acronyms

ABB	Asea Brown Boveri
AC	Actual Cost
ACP	Average Completion Percentage
ANSI/EIA	The American National Standards Institute/Electronic Industries Alliance
B2B	Business-to-business
CA	Control Account
CAM	Control Account Manager
CAP	Control Account Plan
CPI	Cost Performance Index
CPM	Critical Path Method
C/SCSC	Cost/Schedule Control System Criteria
CV	Cost Variance
DoD	Department of Defense
EAC	Cost Estimate at Completion
EV	Earned Value
ETC	Cost Estimate to Complete
EVM	Earned Value Method
EVMS	Earned Value Management System
EVPMS	Earned Value Project Management System
FAT	Factory Acceptance Test
IPT	Integrated Product Team
LOE	Level of Effort

MR	Management Reserve
OBS	Organization Breakdown Structure
PC	Percentage Completed
PERT	Program Evaluation Review Technique
PMB	Performance Measurement Baseline
PMI	Project Management Institute
PV	Planned Value
SAC	Schedule Estimate at Completion
SCM	Supply Chain Management
SPI	Schedule Performance Index
STC	Schedule Estimate to Complete
SV	Schedule Variance
SWOT	Strengths, Weaknesses, Opportunities, Threats
TCPI	To Complete Performance Index
WBS	Work Breakdown Structure

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Chapter 1

Introduction

In business, no matter how good or bad we are today, we have to be better tomorrow. The customers are always demanding more and competitors are consistently getting stronger. For this reason we have to continuously improve ourselves to be able to meet the demands of tomorrow's huge, complex and technically challenging projects. [1] Aspects of productivity and performance are key issues among project's stakeholders as no one wants to make an unprofitable project.

Project management acts in key role when a company wants to deliver successful projects for a customer, thus keeping up good customer experience. Probably the most crucial area of the project management is monitoring ongoing projects and trying to make corrective actions based on the data available. However, what makes this often difficult is to obtain up to date information related to decisions taken in.

> *"The difficulty of measuring progress does not justify the conclusion that it shouldn't be done. You cannot have control unless you measure progress."* [2]

Usually, almost all projects are monitored financially using two figures: planned costs and actual costs. For financial people this may be enough information. However, for project management it is inadequate to explain the progress of the project. Those two numbers just tell whether or not the project is spending its funds. So attention has to be paid also to the quality of information, what it measures and what it tells. Although monitoring a project budget and schedule itself does not make an unprofitable project profitable, it can at the best give an early warning sign about possible problems in the project. Corrective actions can then be made in time to return the project back on track.

The aim of this thesis is to study projects and their management in the case company, and try to find a way to implement earned value management method in their projects. The earned value management method (often referred to as EVM) is a powerful tool for managing and measuring the main three elements of a project; scope, time and cost. [3] Vertenten et al. [4] tell that there are typically three reasons to switch to earned value management method: need to improve the quality of the project management process, to establish accountability for project completion and ensure that progress requirements are being achieved, and to make the flow of information more transparent between the project stakeholders. In this case study, all of these are relevant reasons to look further in this method and how its benefits could be harnessed to the needs of the case company. Furthermore, using a more disciplined approach to managing all types of project can help organizations to succeed [5].

1.1 Description of the problem

The case company operates in marine industry. They develop electrification and automation solutions for marine purposes. They equip these solutions to vessels and fleets for optimal reliability, flexibility and energy efficiency. Since orders for new vessels peaked in 2008, order backlog in the case company has constantly increased which can be seen from the following Figure 1.1.

This leads to new challenges in project management. The number of ongoing projects has increased significantly, thus time and resources available

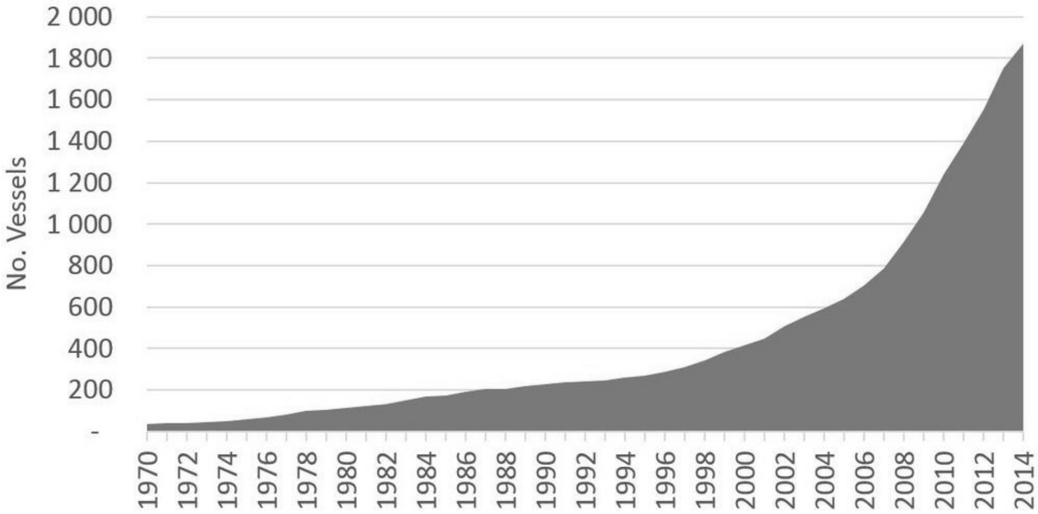

Figure 1.1: Electric propulsion fleet development [6].

to management of one project have decreased. This thesis is based on the need of finding a better way to follow how projects are performing. Currently, the case company determines project status mainly based on the comparison of the actual costs incurred and the budgeted costs. However, this comparison only provides the information whether the budgeted money is spent or not, and it does not tell whether the planned work been completed or not. Thus, in long term projects too often different shortcomings are noticed late in order to make appropriate corrective actions.

Evaluation of the actual progress of a project is mostly based on estimates made by individuals. This leads to varying estimates between persons and between different projects. Moreover, this kind of experience-based assessment of the status of a project is not reliable when new personnel with no experience of the case company's projects are recruited. This thesis is a case study, which main objectives are to provide effective and consistent monitoring and control of projects for the management, and at the same time briefly investigate how earned value could improve forecasting of project's final costs and schedule.

The case company strives to find more efficient ways to manage projects in order to ensure the competitiveness of delivering new concepts, such as DC-grid and dynamic AC. For interested reader, more about these systems can be found from the case company's website: `http://new.abb.com/`.

1.2 The research questions

The research is focused on learning:

- What constraints and difficulties the case company has when implementing earned value management method in their projects?
- What benefits earned value management method could provide in managing case company's projects?

Furthermore, this thesis will investigate the unique characteristics of the case company's projects in order to understand their limitations and needs better. This way an effective approach for implementing earned value management to the projects can be addressed.

1.3 Research methodology

To achieve the objectives of this research, first a comprehensive literature review was conducted on the topic of earned value management and how to effectively implement it on an electrical system project. To support this research also topics of projects and project management were briefly reviewed. Next an application of the earned value management concept was conducted utilizing current case company's projects in order to test the validity of the researched performance metrics. Conclusions and recommendations for future research were developed from this analysis.

1.4 The structure of this thesis

This thesis starts with an introduction and an overall look at the case company background, this is followed by a brief literature review of projects and project management. After that a discussion of the theoretical aspects of the earned value management is conducted. Research starts by defining the typical characteristics of the case company's projects. Then it continues with theoretical and practical application of earned value management concept in case company's project. Finally, results will be discussed and conclusions are stated.

Chapter 2

Background

This chapter introduces the case company this thesis was conducted for. Furthermore, a brief look to company's business and offerings will be taken.

2.1 Case company

The case company this thesis was conducted for is a multinational technology company Asea Brown Boveri (ABB). ABB's roots are in Swedish corporation Allmänna Svenska Elektriska Aktiebolaget (ASEA) that was initially founded in 1883. The ABB Group was formed in 1988 through a merger between Asea AB and Swiss company Brown, Boveri and Cie (later renamed BBC Brown Boveri AG). ABB is a global leader in power and automation technologies, that provide improved performance in a sustainable way for its customers in the utility, industry, transportation and infrastructure sectors. Furthermore, ABB has more than four decades of experience at the forefront of digital technologies, which is why it is also a leader in digitally connected and enabled industrial equipment and systems. It has an installed base of more than 70,000 control systems connecting 70 million devices all over the world.

The company has about 132,000 employees and it operates in approximately 100 countries across three regions: Europe, the Americas, and Asia,

Middle East and Africa (AMEA). ABB's revenue was 33,828 million dollars in 2016. [7]
ABB group is organized into four divisions:

- Electrification Products
- Robotics and Motion
- Industrial Automation
- Power Grids

These divisions are made up according to the industries and customers they serve. More specifically this thesis was made for a local business unit ABB Marine and Ports in Finland which is part of ABB's Industrial Automation division. Globally ABB Marine and Ports has 1,700 employees in 22 countries and it has 23 service centers. Its hubs are located in China, Finland and Norway. ABB Marine has five centers of excellence which are oil and gas, passenger and cargo, propulsion products, ports, automation and advisory. [6]

2.2 ABB Marine Finland

ABB Marine and Ports unit in Finland develops electrification and automation solutions for the marine industry. Furthermore, it is also responsible for the global development of ABB's maritime industry solutions and service business. Its main product is a Finnish innovation: electrical Azipod propulsion system. [8]

ABB Marine Finland organization is divided into three branches: product organization, automation project organization and electrical systems project organization. The product organization is specialized in production and installation of Azipod propulsion products. Azipod is a gearless steerable propulsion system where the electric motor is outside the ship hull in a submerged pod. Azipod propulsion improves vessel safety, energy efficiency, manoeuvrability and performance. [9] The automation project organization delivers integrated marine automation and advisory systems for vessels. This includes power management and control, automation, vessel control, software and analytics. This thesis is focuses only on the electrical systems project organization branch. It delivers complete power generation and distribution systems for all types of vessels. This includes system design, engineering, system studies, manufacturing, commissioning, start-up and after sales service.

Single-line diagram of a vessel's electrical system in Figure 2.1 shows an example and quite typical scope delivered by ABB Marine Finland. Azipods in the figure are under the product organization branch like mentioned above, but everything else is usually delivered by the electrical systems project organization. The automation projects organization's deliveries are not shown in this kind of figure as those are mostly software that integrates all the equipment together in a single working system.

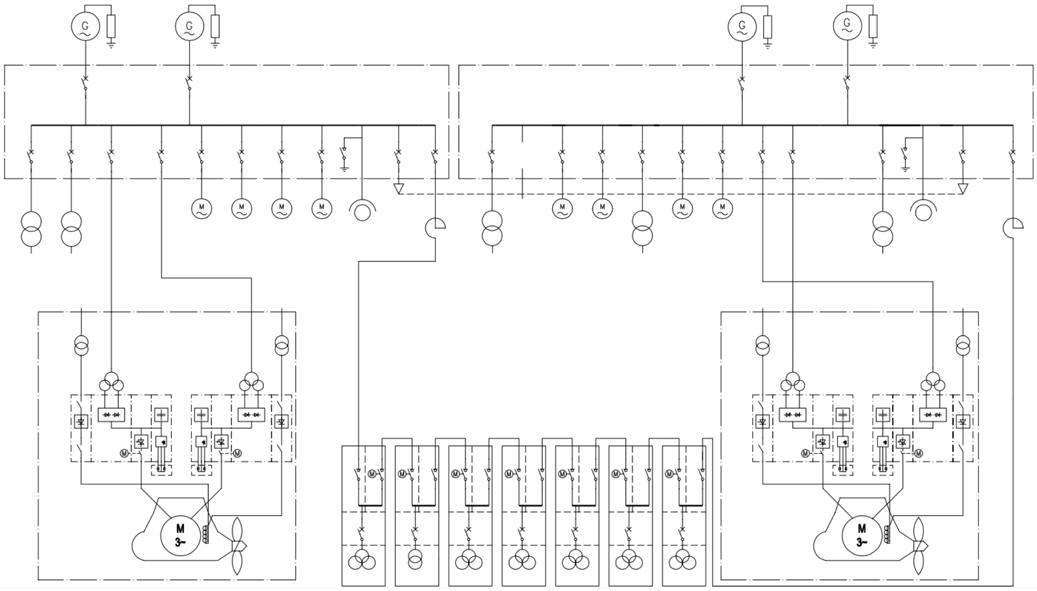

Figure 2.1: An example scope of a project [10].

This single-line figure is not opened up any further, but it is shown to give an idea what kind of projects the organization this thesis is conducted for is delivering. To get this whole system working, it requires lots of engineering and project management, multiple suppliers, plenty of designing and testing etc.

Chapter 3

Projects and project management

In general, different kind of projects either private or business related are part of our everyday lives. But what exactly is the definition of a project, and what is needed to manage it successfully? This chapter will provide an answer to these questions in common level. Firstly, the definition of a project will be discussed. Typical elements and features for every project are disclosed. Secondly, project management, why it is needed and its objectives are discussed. The Project Management Institute's guide for project management [11] will be introduced briefly, as it creates the basis for project management in the case company.

Based on the knowledge available in this chapter, it is easier to require features what earned value management should offer in terms of project management and to investigate general and unique attributes in the case company's projects.

3.1 What is a project?

To discuss about project management, it is essential to first understand the concept behind a project.

"A project is a temporary endeavour undertaken to create a unique product, service, or result continuous business operations." [11]

Furthermore, a project has a fixed budget and schedule, and projects can be different in size, large or small and involve one person or thousands of people. [5, 12]

The following attributes help to further define a project as they are typical for every of them:

- **Objectives:** A project has a clear and well-defined objective or set of objectives. Once those have been achieved, the project ends. [5, 12]

- **Life cycle:** A project is not continuous operation, but rather it must have a definite beginning and ending. The end point can normally be derived from the project objectives. [5, 12]

- **Entity:** A project is a clearly defined entity in which responsibility is centralized to a certain point, even if there would be a lot of different interest groups and parties involved. [12]

- **Teamwork:** A project requires teamwork. Groups may consist of individuals who represent different organizational units and nationalities. [12]

- **Phasing:** Every project has few different phases, which taken together represent the path a project takes from the beginning to its end. They are generally referred to as the project ”life cycle”. These phases are equally important and they all contribute to the overall success of the project. [12]

- **Uniqueness:** Everything, people, places and other circumstances change over time, which makes every project unique. Although repeat projects may have some repetitive elements in project deliverables and activities, this repetition does not change the fundamental, unique characteristics of the project work. [11, 12]

- **Progressive elaboration:** Although a project needs to be planned beforehand, it will face a wide range of redefining during its life cycle.

Redefining may occur when for example the time passes and project details become more clear, or the customer wants to change something. Some of the changes may not affect the project at all, when on the other hand some other changes may totally redefine its nature and objectives. [5, 12]

- **Consequential principle:** In the current phase of the project, it is not certain what will happen in the next phase. The activities in the next phase will always be influenced by the results of the previous phase as the details become more accurate when the work progresses. [12]

- **Sponsor/customer:** A project may have many interested parties or stakeholders, but some of them must take the primary role of sponsorship. The project sponsor/customer usually provides the funding as well as direction for the project. [5, 12]

- **Unity and variety:** A project requires resources often from various areas including technology, labor, material, software and other assets. However, these variables have to be in particular relation to each other so that the project works properly. [5, 12]

- **Subcontracting:** Part of the project work is usually done using subcontractors. The amount of subcontracting used is proportional to the scope of the project. [12]

- **Risks and uncertainties:** Every project will have some level of risks and uncertainty, as those are substantial features of the nature of the project work. Due to uniqueness of a project, it is sometimes difficult to define its objectives clearly, estimate when it is completed or determine its final cost. All this kind of uncertainty increases the probability of risks to take place. [5, 12]

Even though a project is a commonly used term, the final products can be completely different between different projects. The result can be anything depending on the area of application from a play house to a power plant. Furthermore, the end result does not always have to be some tangible product, it can also be a solution or service. Even though projects are temporary, it does not apply to the result created by the project. Most of the projects are undertaken to create a lasting outcome. [5, 11, 12]

3.1.1 Project constraints

Every project is constrained in different ways, but the most typical are scope, time and cost constraints. These three elements are sometimes referred to in project management as the triple constraint. The triple constraint typically is shown as a triangle, shown in Figure 3.1. It is a way of showing that each of the three elements are of equal importance, at least in terms of project control. If one facet of the triangle is changed, almost invariably one or both of the others is affected. [5, 13, 14]

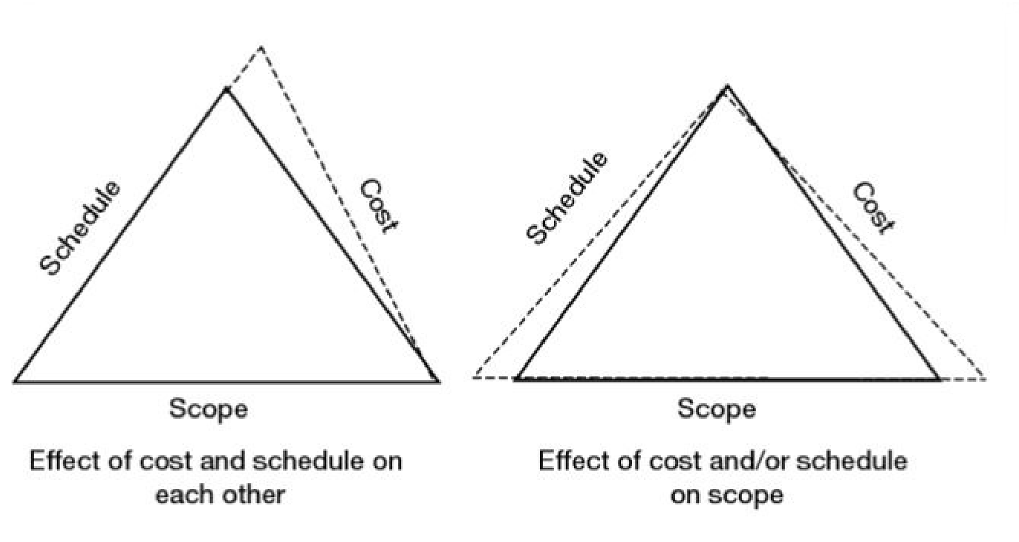

Figure 3.1: Classic project constraints and how they can affect each other [13]. Scope is the sum of the products and services to be provided. Cost is all the resources (money, labor, etc.) needed to complete a project. Schedule is the time it takes to complete a project.

Figure 3.1 illustrates the relation between the elements of the triple constraint. Scenario in the left triangle: the schedule is extended which means that the costs must increase due to the additional resources to accommodate or reduce the schedule overrun. Scenario in the right triangle: reducing schedule and costs back to the original estimates, the scope of the project must be reduced.

To create a successful project, a project manager and team must keep the three elements of the triple constraint in balance. However, this is easier said than done as these three elements are often competing as illustrated in Figure 3.1. The balancing is a juggling act that is often difficult and requires various skills from the project manager such as communication, risk management, contracting, reporting, selling, analysing and many others. [5, 13]

The concept of the triple constraint is well-known, but the project constraints are not limited to those three. The specific project characteristics and circumstances can influence the constraints on which the project manager needs to focus. Project Management Institute's document called ”A Guide to the Project Management Body of Knowledge (PMBOK® [11]) suggests these three constraints but in addition quality and risk. [5, 11]

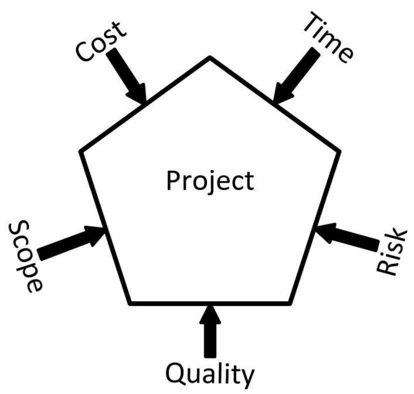

Figure 3.2: Project constraints according to PMBOK® Guide [11]. Quality means the accepted level of defects in the products or services. Risk is the amount of uncertainty taken in the project.

These two additional constraints often affect each other as well as the scope, time and cost goals of the project. In short, all the project constraints shall be kept in mind during the course of the project in dealing with changes, contingencies, assumptions, re-planning and issues that may arise. [13]

3.1.2 Project life cycle

Every project has a life cycle, or otherwise it would not be a project. Like mentioned earlier in this chapter, project's life cycle consists of a handful of different phases. Each phase is characterized by a distinct set of activities that take the project from the concept to its conclusion. However, there is no single standard for life cycle models. Thus, the names used for the phases and the number of phases differ from industry to industry or even according to an organization's preference. Regardless of the variation of a life cycle model used, they all share the basic elements. [12, 13] In Figure 3.3 is illustrated a project life cycle with five phases: concept, planning, design and development, implementation and closeout. Each of the main phases has it own sub phases, steps or states, and these usually are defined by an organization to serve its way of defining and developing projects. [13]

It is typical for the phases of a project to overlap a bit, like is shown in Figure 3.3. Sometimes it is necessary to return to the previous phase, or some preliminary work for the next phase is started beforehand. Therefore, it is not always clear in which phase the project actually is. [12]

Next, a closer look to these five phases in the project life cycle model shown in Figure 3.3 will be taken.

Concept

The project is just beginning and in this phase the data is being gathered. Usually, there is a previous phase to select the project in which, in almost every case, a project manager is not involved. In a business case the project selection is usually done by conducting a feasibility study ("can we do the project and should we do the project?") [15]. The project manager will

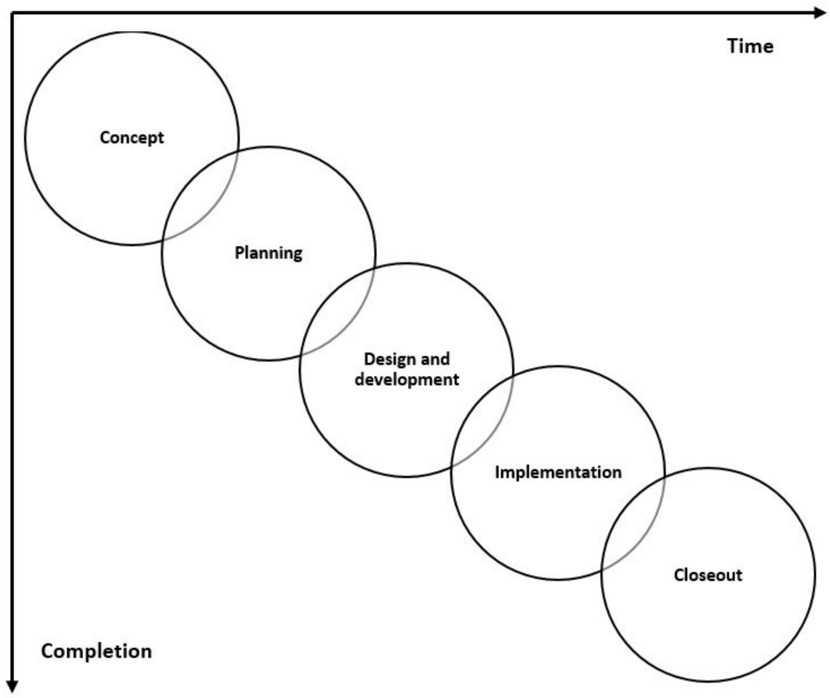

Figure 3.3: An example of a project life cycle.

be appointed during the concept phase after decisions have been made to undertake the project and for what purposes. After nomination, the project manager will determine what the requirements are and what resources are needed. [13]

Planning

The key to a successful project is in the planning. In the planning phase comprehensive plans are developed for cost, scope, duration, quality, communication, risk and resources. Thus, typical activities in this phase are creating work break down structure (WBS), developing schedules, developing cost estimates, etc. [13–15] In this phase the participating work groups are identified, and the project team begins to take shape. [13]

Design and development

In the design and development phase the project blueprint is further developed in as much detail as possible. Design meetings are conducted to gather all information required to create the design documents. After the documents are reviewed and approved, the actual work on the project deliverables can begin. In this phase, the project manager keeps track how the project is progressing and implements control strategies to keep actual progress as close to the plan as sensible. [13]

Implementation

The project plan is put into motion and the project deliverables, or products, are implemented. The project manager continues to monitor project progress and to make appropriate adjustments based on variances from the original plan. All variations from the original plan should be recorded and modifications to the plan published. Throughout this phase, project sponsor and other key stakeholders should be kept informed of the status of the project. Once all the deliverables have been produced, any open problems needed to resolve are resolved and the customer has accepted the result, the project is ready for closure.

Closeout

Closing the project is often considered to be the most difficult phase. Project manager loses team members to other projects as the current project is seen to be winding down and organizational focus is moved to other ongoing projects. [13] However, this phase is as critical to the success of the project as any other phase, just in a different way. The emphasis is on releasing the final deliverables to the customer, closing out administrative and contractual paperwork, releasing project resources and communicating the closure of the project to all stakeholders. And to make future projects more successful, usually a lessons-learned study is conducted. This way the wisdom of experience is transferred back to the project organization. [13–15]

3.1.3 Measuring success

"A successful project achieves the objectives set for the end product in accordance with the planned schedule and the agreed costs." [12]

The success of the project must be assessed both in terms of the end product and production process. It is easy to see how well project's schedule and budget objectives were achieved, because they are reported using measurable units. On the other hand, the success of quality and scope objectives is a bit trickier to be measured as they are more depended on what is valued. In addition, the achievement of them is finally defined outside of the project. The project can deliver a product that is one to one with the descriptions, but the customer is not satisfied because the description was defined inadequately. Thus, a project is often considered to be unsuccessful if the expectations for the project have not been met. Figure 3.4 illustrates the general problem in defining the end product. For a successful project it is critical that the project team and the customer have an agreement about the content and characteristics of the final product right from the project start. [12]

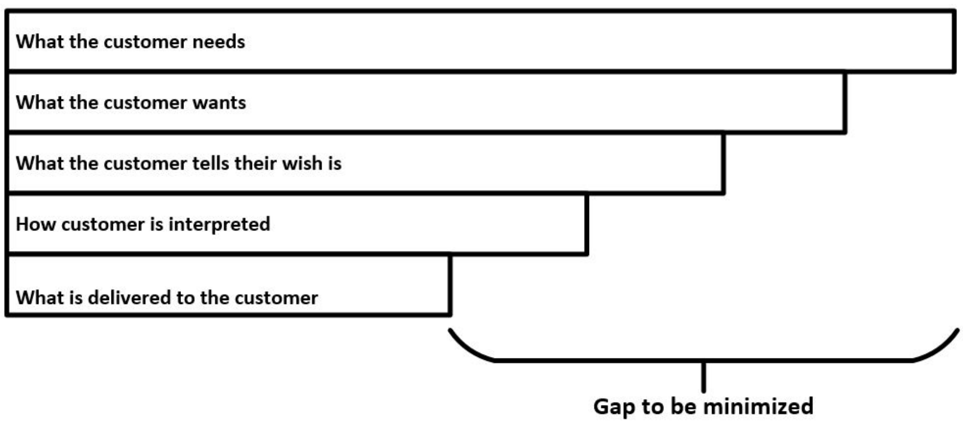

Figure 3.4: The problem in defining the end product. Good communication between the company and the customer is one effective way to minimize this gap.

In the end, project success is all about balancing the project constraints shown in the Figure 3.1 (or in Figure 3.2) so that the customer and all the stakeholders are satisfied. In the best scenario the project finds success in all the sections, but most often the success in one section is done at the expense of some other section. [12]

3.2 Project management

In order to be successful, an organization must be able to create projects that produce desired results with the authorized time and resources. As a result, businesses are increasingly driven to find individuals who are capable of managing projects. [14]

> *"Project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements."* [11]

The term *"management"* refers to the process of getting things done, effectively and efficiently, through and with other people [16]. Project management means basically the same but the focus is on a certain project or set of projects and not on an organization for example. And projects are often more schedule-intensive than most of the tasks that general managers handle [2].

Project management can be thought of as the process of leading a project from its initiation through its performance to its closure. And to succeed in this process, a project manager must have a number of skills such as planning, coordination, communication, time management, leadership, negotiation, etc. [12, 14] The process includes five groups of processes as is illustrated in Figure 3.5 and which are described next.

Initiating processes

Once a project is decided to be undertaken, it must be initiated. This includes number of activities such as: clarifying the business need, creating project

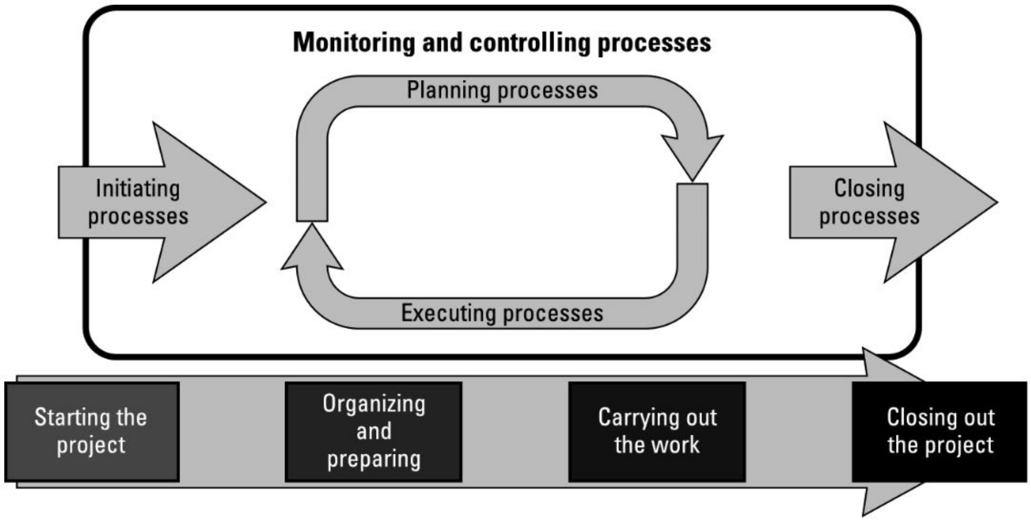

Figure 3.5: Project management activities during a project life cycle [14].

character, defining high-level expectations, resourcing budgets, establishing scope boundaries, identifying audiences that may affect in the project, etc. [2, 14]

Planning processes

A project cannot be controlled without proper plans or at least it too often leads to project failures. That is why it is important to use proper time on planning processes such as detailing project scope, schedule, resources and risks as well as preparing project communications and quality plans, defining management of external purchases of goods and services, etc. [2, 14]

Executing processes

Project execution can be thought to consist of two parts. Firstly, it is to execute the technical work that must be done to create the final product of the project. Secondly, executing also refers to implementing the project plan. [2, 14]

Monitoring and controlling processes

Monitoring and controlling are two separate processes, but because they go hand in hand, they are often considered one activity. Monitoring is needed in order to keep track how the project is progressing. Whilst controlling processes are there for comparing project's monitored status to planned status, and then taking corrective actions for any deviation from target. [2, 14]

Closing processes

Closing processes include all informal, formal and administrative actions needed for ending all project activities. Furthermore, one very important task is to do a lessons-learned review to avoid same failures and repeat successes in future projects. [2]

3.2.1 Project Management Institute

The Project Management Institute (PMI) is a not-for-profit professional membership association for people who manage projects. PMI provides globally recognized standards, certification programs, extensive academic and market research programs, chapters, as well as volunteer and professional development opportunities. [17] Their guide, PMBOK® Guide, provides guidelines for managing projects and defines project management related concepts. Furthermore, it describes the project management life cycle and processes, as well as the project life cycle. [11] In short, it is intended to include a minimum body of knowledge that is needed by an effective project manager.

PMBOK® Guide [11] defines the project management using the same five process groups mentioned in Section 3.2, together with ten general areas of knowledge and 47 actual project management processes. Brief summaries of these knowledge areas will be provided next. Table 3.1 shows how these ten knowledge areas are related to the five project management process groups and how those 47 processes are divided into that matrix. For interested readers, a complimentary PDF download of this standard is available to PMI members on their website: `www.pmi.org`.

Project Integration Management

Processes and activities to identify, define, integrate, unify, and coordinate the different project management processes and activities within the project management process groups. It ensures proper planning, execution and controlling of the project. [2, 11]

Project Scope Management

Processes that define the boundaries of the project scope so that the project includes all the work required to complete the project successfully, and no more. In addition, project change control procedures are specified. [2, 11]

Project Time Management

Processes that ensure the project is completed on time. This is achieved by sequencing and scheduling activities into a realistic schedule for the project. [2, 11]

Project Cost Management

Processes that ensure the project completes within the authorized budget. This involves cost estimation of resources, such as people, equipment, materials, traveling, etc. After estimation, costs are budgeted and then tracked for the duration of the project. [2, 11]

Project Quality Management

Project quality management includes both quality assurance and quality control. This means that a plan to meet quality requirements is developed and results are monitored to see if they conform to the requirements. [2, 11]

Project Human Resource Management

Processes that organize and manage the project team. This involves identifying the people needed to do the job, acquiring them and defining their roles, responsibilities and reporting relationships. [2, 11]

Project Communications Management

Processes that specify how and when team members and other stakeholders communicate and share information both internally and externally. [2, 11]

Project Risk Management

Processes that conduct risk management activities on the project. These activities include risk identification analysis, response planning, monitoring, and control. The aim of these actions is to increase the likelihood of positive events, and to decrease the likelihood of negative events in the project. [2, 11]

Project Procurement Management

Processes that manage the procurement of products and services for the project. This includes determining items that must be procured issuing requests for quotations, selecting vendors, administering contracts and contractual obligations placed on the project team by the contract. [2, 11]

Project Stakeholder Management

Processes that are required to keep up a good stakeholder satisfaction. This includes identifying the people, groups, or organizations that may have influence or be influenced by the project, analysing stakeholders interests and what impact they have on the project, developing management strategies to effectively engage stakeholders in the project execution and decisions, etc. Furthermore, high importance is set on continuous communication with stakeholders. [11]

Table 3.1: Mapping of project management process and knowledge areas according to PMBOK® Guide 5th edition. [11]

Knowledge Areas	Project management Process Groups				
	Initiating Process Group	**Planning Process Group**	**Executing Process Group**	**Monitoring and Controlling Process Group**	**Closing Process Group**
Project Integration Management	-Develop Project Charter	- Develop Project Management Plan	- Direct and Manage Project Work	- Monitor and Control Project Work - Perform Integrated Change Control	- Close Project or Phase
Project Scope Management		- Plan Scope Management - Collect Requirements - Define Scope - Create WBS		- Validate Scope - Control Scope	
Project Time Management		- Plan Schedule Management - Define Activities - Sequence Activities - Estimate Activity Resources - Estimate Activity Durations - Develop Schedule		- Control Schedule	
Project Cost Management		- Plan Cost Management - Estimate Costs - Determine Budget		- Control Costs	
Project Quality Management		- Plan Quality Management	- Perform Quality Assurance	- Control Quality	
Project Human Resource Management		- Plan Human Resource Management	- Acquire Project Team - Develop Project Team - Manage Project Team		
Project Communications Management		- Plan Communications Management	- Manage Communications	- Control Communications	
Project Risk Management		- Plan Risk Management - Identify Risks - Perform Qualitative Risk Analysis - Perform Quantitative Risk Analysis - Plan Risk Responses		- Control Risks	
Project Procurement Management		- Plan Procurement Management	- Conduct Procurements	- Control Procurements	- Close Procurements
Project Stakeholder Management	- Identify Stakeholders	- Plan Stakeholder Management	- Manage Stakeholder Engagement	- Control Stakeholder Engagement	

3.3 Discussion

Although all projects are unique entities, between them is recognizable features and the implementation processes are similar. Each project goes through similar phases during its life cycle and is constrained by the same factors introduced in Subsection 3.1.1. These things have made it possible to make general guidance related to project management. However, to gain expertize in one company's projects and their management, he/she should be able to recognize those projects' special characteristics and unique attributes. This way project management can be focused on the most important needs in the projects, and the management techniques and tools can be customized to best support those needs.

Project failure is usually the result of inadequate management and management methods, not the result of technical reasons. [12] This imposes requirements for the project management methods. In order to sufficiently cover management of all the critical elements and activities in a project, it often requires integration of multiple management techniques and tools. However, this increases the complexity and thus the effort required from the project management to handle the whole system. For this reason companies are searching for more efficient management methods, which can provide the same or even better information and controllability of the project with less effort. In the middle of all the performance enhancement one also must remember the human aspect as the project workers are usually efficient and productive when they are treated well. The people who are required to use these new methods must see its benefits in their everyday work. Otherwise motivation to commit on using them will start slowly decrease.

Chapter 4

Earned Value Management method

The main objective of this thesis is to evaluate whether Earned Value Management method (EVM) is feasible in case company's project management and what benefits it could offer compared to the effort its implementation needs. Firstly in this chapter, the difference between EVM and traditional cost management will be discussed. Secondly, this chapter will provide a comprehensive literature review of EVM, which is then the base for the evaluation done in the following chapters.

4.1 Traditional cost management vs. EVM

Most projects keep track of their budget and actual expenditures and by comparing these two quantities is then stated how well the project is performing financially. Fleming et al. [18] describe this two-dimensional approach as traditional cost management. From monitoring point of view, this approach is very simple to use, due to the fact that planned and actual expenditures are almost without exception measured and logged in any sort of projects. And what comes to control decisions with this approach, those are basically made relying on the following idea:

If $Budget$ € $-$ $Spent$ € ≥ 0 €, no corrective actions are required, else yes.

However, such a comparison does not provide a measure of value obtained and delivered for the actual expenditures. [18, 19] In their findings Fleming et. al [18] point out that there is an important distinction between the data available when using the traditional cost management and for using EVM. All that can be concluded by comparing budget and actual costs is that whether or not the projects are meeting the expenditure of funds they set out to do. Moreover, this measure does not tell what physical work is accomplished for the money spent or is the cost performance of projects getting better or worse. [20] The fact is that too often the money is spent in a project and there is less than should be to show for it. This is where EVM makes a difference, because it also includes the actual work accomplished, also known as the earned value, into the measurements. [19] Figure 4.1 illustrates the main idea and benefit between traditional cost management and EVM.

As seen from Figure 4.1, if those shaded bars would not exist the project could have two possible scenarios to be in based on the planned cost and actual cost: project is behind the schedule because it has spent less money than planned; project is doing very nicely because all the planned work has been completed for a cost that is well below the budget. However, by taking the earned value into account the figures are indicating that the project is in fact well behind schedule and costing more than was expected for what has actually been achieved. How this conclusion was made and more information about earned value management will be discussed next in this chapter.

4.2 Fundamentals of EVM

"Earned Value is for projects...it is not for continuous business operations" [18]

EVM supports a project manager by integrating three critical elements of a project: cost, time and scope. Furthermore, it is designed to give project manager an overview of project's performance by allowing calculation of cost and schedule variances and performance indices. [3] Monitoring the progress

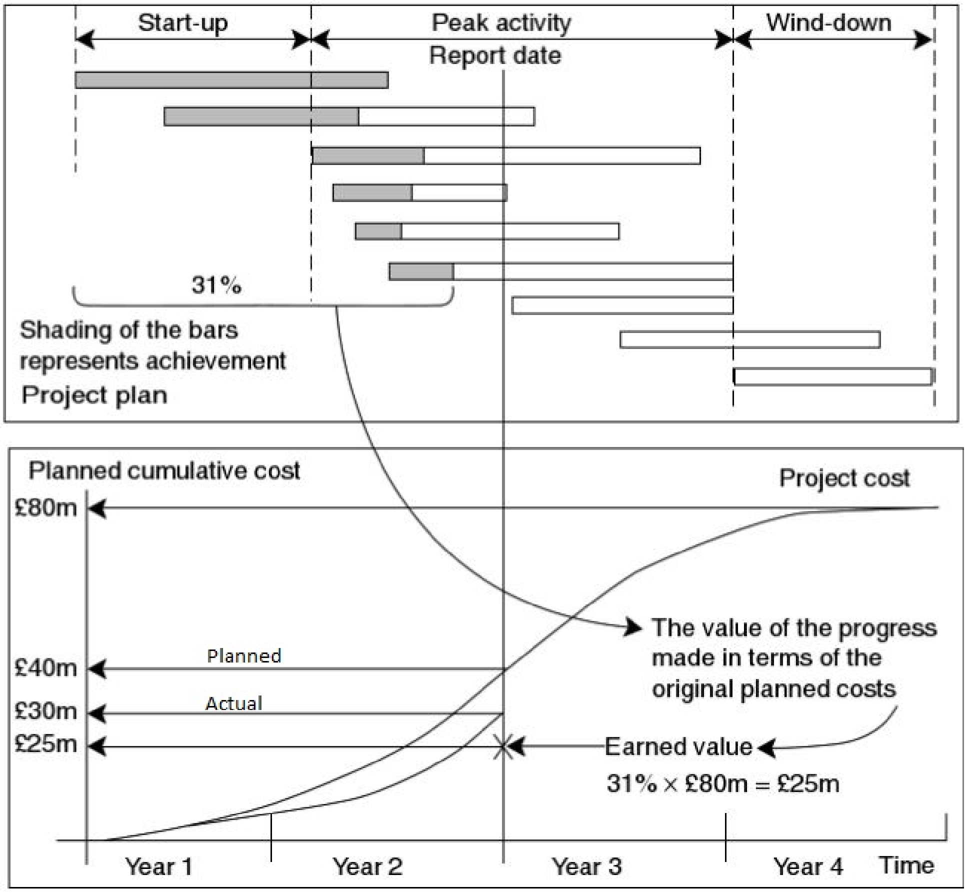

Figure 4.1: Adding the earned value to the cost curves of a project. A determination of whether the project is undercutting or overrunning its budget can now be made. [21].

of a project should not focus only on cost and time variances prior to the review date, but also to establish the actual project status based on forecasts of final project performance [22]. However, using EVM the management can quite accurately predict a major final cost of a project in very early stages of a project [23]. As a result of these calculations EVM provides project manager an early indication of poor performance that needs corrective actions and opportunities that might be exploited [19]. EVM therefore encompasses both performance measurement (the program status) and performance management (corrective action plans based on the variances).

The key to understanding of Earned Value Management concept is to understand its three main dimensions: [13, 21, 24]

1. The budget for the work scheduled or the planned value of work done (also referred as "planned value, PV")

2. Actual cost of work performed (also referred as "actual cost, AC")

3. Value created according to the work done (also referred as "earned value, EV")

The values are also shown in Figure 4.2. All the variances and performance measurements are then easier to remember and use, because they can be determined by looking these three quantities and their proportions to each other. All Earned Value components and equations for variances and indices will be introduced later in Section 4.4.

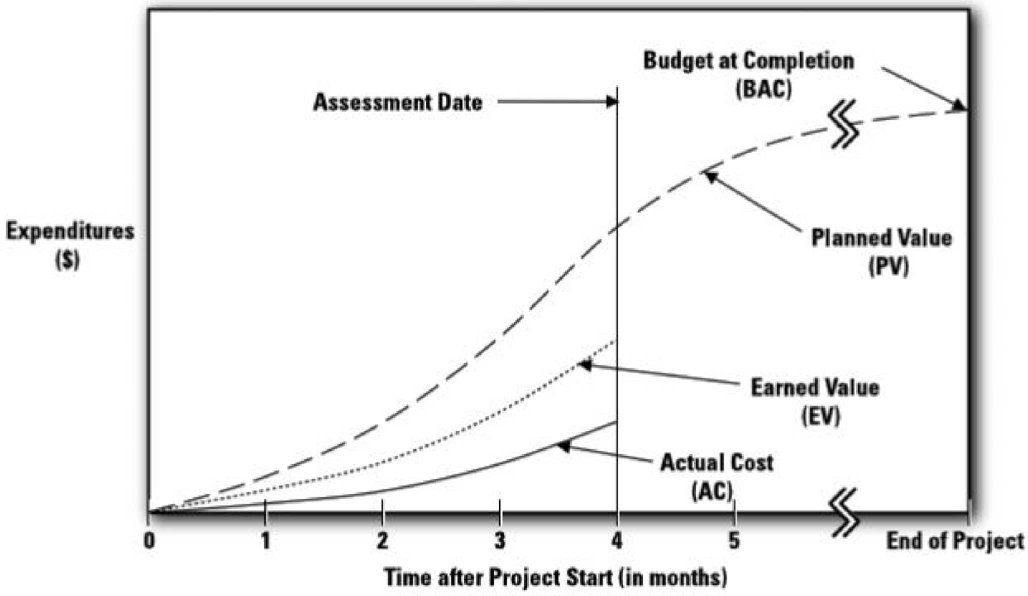

Figure 4.2: Values that form the basis of Earned Value Management measurements [14]. Budget at completion will be introduced in Section 4.4.

4.3 History

Industrial engineers on the factory floor in America were the pioneers of Earned Value concept back in the late 1800s. They measured their work performance efficiency in the factory using a three dimensional approach. They had so called ”planned standards” as a baseline for the performance measurements, and then ”earned standards” achieved was measured against the ”actual expenses” incurred to get accurate view of the work performance in the factories. What they did not know was that they were actually employing EVM in its most fundamental form. [18]

Around the late 1950s, the Program Evaluation Review Technique (PERT) emerged from the U.S. Navy’s Polaris Missile Program as a risk management and network scheduling tool. It approached project management from two ways: creating a logic flow diagram for a new project to simulate its development planning, and assessing the statistical probabilities to actually achieving that plan. [18, 20]

In 1962, the advocates of PERT were determined to expand the concept to the next level by adding resources to the networks. The result went by the name PERT/Costs and it allowed the management of both cost and time dimensions of a project. However, at the time neither the computer hardware nor the software programs were available to support these new concepts which constituted the major early difficulties. Both the original PERT and PERT/Cost failed to survive by the mid-1960s. Today, the term ”PERT” is still used but only as a generic title for any scheduling network method. Although, these techniques vanished from the scene the earned value concept’s potential was recognized among communities which led to further research. [18, 20]

In 1967, agencies of the U.S. Federal Government introduced EVM as an integral part of the cost/schedule control system criteria (C/SCSC). The criteria were brought together by the U.S. Air Force in early 1960s and they were used in large acquisition projects which typically hold high risks. [3, 18]

The C/SCSC consists of 35 criteria that incorporate the earned value concept and were imposed on any private contractor who wanted to be chosen for U.S. Federal Government's new major systems contract that exceeded established financial thresholds [18].

U.S. federal government has used C/SCSC effectively and successfully in its in-house projects since their release. However, the private sector did not adopt the method very well at first because the methodology was viewed too excessive bookkeeping rather than a true management tool. In the 1996 the U.S. Federal government made their effort to encourage private sector to use EVM by discarding C/SCSC and turning toward a more flexible Earned Value Management System (EVMS), also known as Earned Value Project Management System (EVPMS). It contained 32 criteria instead of 35 and each of them rewritten in a more palatable form. In June 1998 these 32 EVM criteria were formally issued to the public as the American National Standards Institute/Electronic Industries Alliance standard ANSI/EIA-748. Furthermore, PMBOK® Guide [11] provided simplified EVM formulas and terminology. [3, 18]

The viability of earned value management as a best-practice tool has been tested, improved and adopted by not only the U.S. government but also an increasing extent by private industry. It is a technique that project managers everywhere can use. [18]

4.4 Key components

In this section the key components of EVM are introduced. The notation used is The American National Standards Institute/Electronic Industries Alliance standard ANSI/EIA-748. Other used standard is U.S. Department of Defense cost/schedule control systems criteria (DoD C/SCSC standard). Comparison of the acronyms used in these two standards can be found from appendix A.

4.4.1 Planned value

Planned value (PV) is the authorized budget for accomplishing a work package or project related to the schedule. It is the value that should have been achieved at any given point in time. In other words, cumulative PV represents the estimated total cost of all the work packages of the project and it is usually referred to as the S-curve. Planned value is also the performance measurement baseline (PMB) for an earned value project. [3, 13, 24]

Budget at completion

Budget at completion (BAC) is the same as PV of a work package or project at completion. Thus, it is the total expected cost for all the work at project completion. [3, 13, 24]

4.4.2 Actual cost

Actual cost (AC) is the real amount of money spent in completing a work package or project in a given point in time. It includes the labor salary, the cost of materials and all other direct costs. [3, 13, 24]

4.4.3 Earned value

Earned value (EV) is the value that separates EVM from other project management methods. It is the estimated value of all the progress achieved on the work packages or project up to the reporting date. It represents what has been earned in reality, not simply what has been spent. EV is calculated by multiplying the total budgeted value of the work package or project by its completed proportion. This portion is called the Percentage Completed (PC). Equation for EV is therefore following: [3, 13, 24]

$$EV = PC \cdot BAC. \tag{4.1}$$

Earned value is easy to illustrate with a simple example. Imagine an project (or activity) that has a budget of 1000 €. In the end of one reporting period, 30% of the project has been completed with expenditures of 400 €. EV in this case equals $EV = 30\% * 1000$ € $= 300$ €. What it indicates that EV (300 €) is less than AC (400 €) discussed in Section 4.5.

4.5 Project monitoring

"Project performance should be measured throughout the life of the project" [25]

In an ideal situation, all the values, PV, AC and EV should be equal in any given point in project's life time. However, due to some unforeseen events, this is usually not the case. Work packages may take more or less time to complete than was originally estimated, machines can break, employees may get sick, delivery problems with suppliers etc. All such events will cause deviation to project measurements from the performance measurement baseline (planned values). To accurately measure these cost and schedule deviations in a project and between different projects, various indicators were developed into the EVM concept. Figure 4.3 gives a quick image how the indicators are related to EVM's key components.

The most important EVM indicators are discussed in following subsections. Furthermore, less known and used indicators will be introduced briefly in the end of this section.

4.5.1 Variances

Variance indicators are EVM's measures that closely resemble those traditionally used and those that the management looks for. For that reason they are also the most used and the most useful project performance measures. [13] EVM has two different types of variance; cost and schedule variances. It is suggested that these variances are calculated at the lowest level of detail

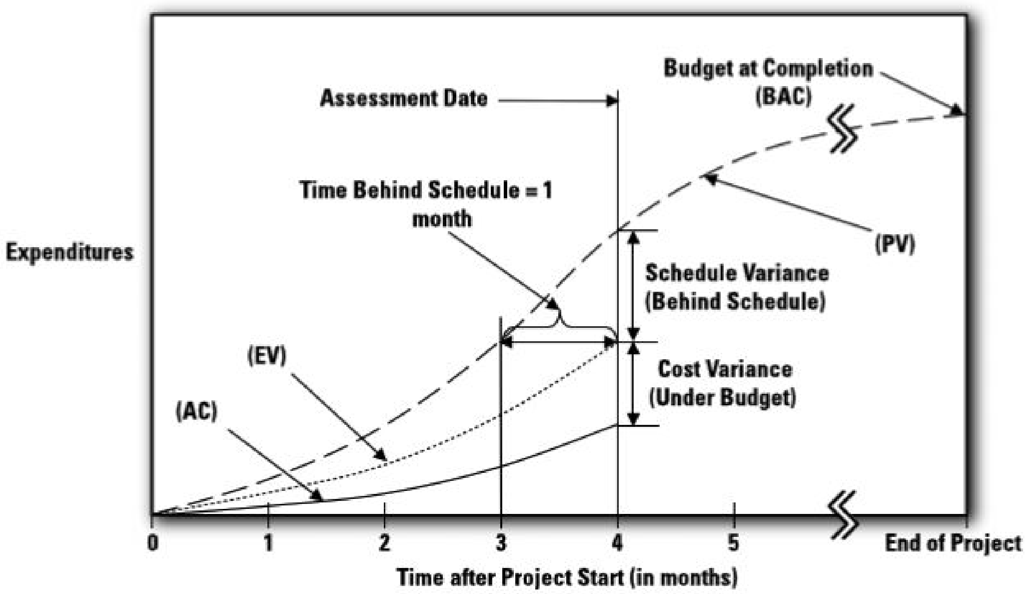

Figure 4.3: EVM performance indices and variances [14].

within the project and progressively summed through the upper levels of the project. This way the project management is able to see where the cost or schedule performance problems are occurring and to make corrective actions. [21]

Cost Variance

The cost variance (CV) is the numerical difference between the earned value of the work accomplished and the actual costs incurred to accomplish that work. CV can be calculated using the following equation: [14, 19, 21]

$$CV = EV - AC. \quad (4.2)$$

A negative CV indicates that the project is over budget, a positive value would indicate the project is under budget and a CV of zero indicates the project is exactly on budget.

Schedule Variance

The schedule variance (SV) is the numerical difference between the earned value of the work accomplished and the planned expenditure to accomplish that work. Thus, the equation for calculating SV is as follows:

$$SV = EV - PV. \tag{4.3}$$

A negative SV indicates that the project is behind schedule, where as a positive value indicates the project is ahead schedule and if the SV is zero the project is right on schedule.

4.5.2 Performance Indices

Where the cost and schedule variances are the simplest of EVM calculations some further numerical information can be derived which may be even more helpful. These are called performance indices. They are a good way to inform the management how a project is performing relative to actual expenditures or planned progress. Furthermore, these indices are also used to forecast future performance of the project. [13, 19]

Cost Performance Index

The cost performance index (CPI) is the most important tracking method in EVM [23]. It shows the relation between the earned value of the work accomplished to the actual costs incurred to accomplish that work, sometimes referred to as the project's cost efficiency. The CPI can be calculated by using the equation: [14, 19, 21]

$$CPI = \frac{EV}{AC}. \tag{4.4}$$

In practice the CPI shows the real value of every euro spent on the work in the project. A CPI less than one means that the project is spending more than is being earned, a CPI greater than one means that the project is achieving more value than is being spent and a CPI of exactly one means the project is right on budget.

The CPI is a good predictive tool for project management because it has been noticed to be remarkably stable over the course of most projects. The DoD studies show that the CPI will get stabilized after the 20 percentage completion point of a project. [23]

Schedule Performance Index

The schedule performance index (SPI) shows the relation between the earned value of the work accomplished to the planned cost of the work. It is also referred as the project's schedule efficiency as it reflects the relative amount the project is ahead or behind schedule. Equation for calculating SPI is as follows: [14, 19, 21]

$$SPI = \frac{EV}{PV}. \tag{4.5}$$

A SPI greater than one means that the project is running ahead of schedule, a SPI less than one means that the project is lagging behind schedule and a SPI of exactly one means that the project is right on schedule.

4.5.3 Other measurements

Table B.1 in Appendix B includes other useful EVM measures that can help project management to get better vision of the overall health of the project, predict the possible future costs and determine how close the current plan is likely to be to the original projections. Noteworthy is that EVM is particularly useful in forecasting the final costs and schedule for a project, based on the actual performance up to any given point in the project [3].

4.5.4 Limitations

SV as a measure of progress has been criticized by different authors due to the fact that it uses monetary units as an analogue of time, which may not be strictly true. Moreover, it has been found that the SV looses its predictive ability over the last third of the project's life cycle and in the end it always converges to zero because EV equals PV at project completion. Due to the fact that the SPI also uses monetary units to indicate time-based performance, it has the same issues as the SV. Only difference is that instead of zero the SPI always converges to one at project completion. This has led to new concept called Earned Schedule that strives to overcome these anomalies with the SV and the SPI. [26, 27] Nevertheless, the SV and the SPI can still provide valuable information to project management if their limitations are properly addressed.

4.5.5 Data presentation

In general presenting lots of numbers in a table for example, is neither the most informative nor intelligible way of presenting them. That is why it is suggested to use different graphical displays for analysis of the EVM metrics. Graphs of variances and indices over time provide valuable indicators of developing trends within the project and of impact of any corrective actions as well as the overall position of the project in terms of time and money. Furthermore, these graphs make it easier to explain these phenomena to different levels of project management.

The key components of EVM, PV, AC and EV, are usually plotted cumulatively and all in the same graph like in Figure 4.2 and Figure 4.3. From cost and schedule point of view a project has four alternative positions to be in. In Figure 4.4 is shown how these components would look like in all four scenarios.

Because the variances are not relative values but numerical differences between EVM's key components, they are often plotted in the same graph with these cumulative spending curves of PV, AC and EV. Figure 4.3 is a good example how the variances can be visually detected between the cumulative spending curves.

The CPI and SPI are also usually plotted to support analysis of the

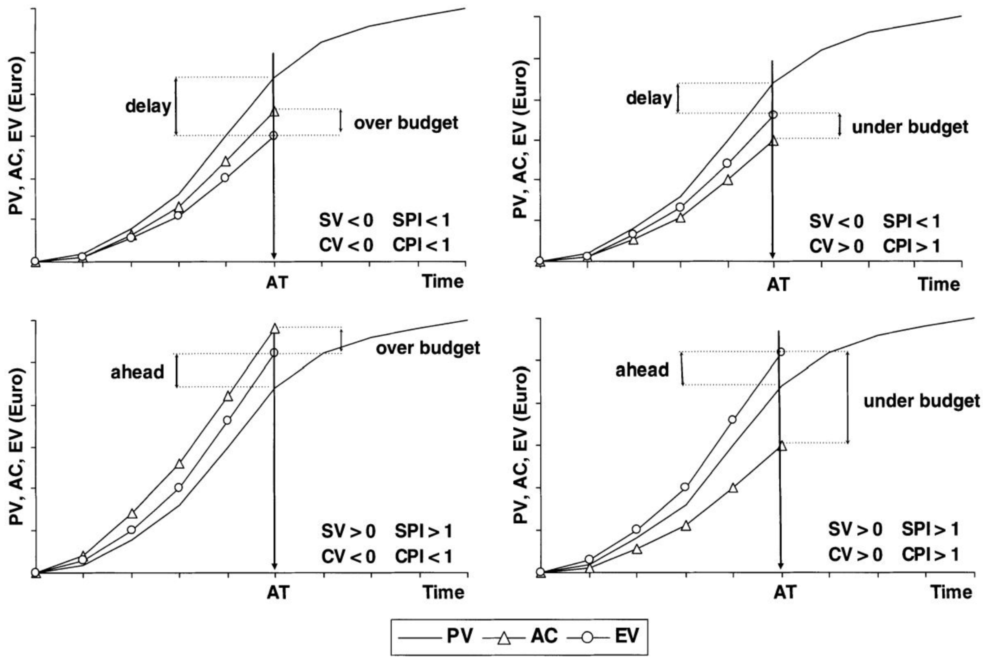

Figure 4.4: The key components of EVM for a project under four scenarios. Top left: late project, over budget; Top right: late project, under budget; Down left: early project, over budget; Down right: early project, under budget. [26]

project but in their own graph for reasons of clarity. They need different scale on graphs as their values are relative and usually vary close to one. Figure 4.5 shows typical graphs of the CPI and SPI and how they would evolve over time in the four different project scenarios shown in Figure 4.4.

However, these are naturally not the only ways to present the data but the project management can develop their own graphs that support best their needs and preferences. In Figure 4.6 is shown one alternative way to plot the CPI and SPI in a quadrant diagram.

Different graphs have their own pros and cons which is why it is important to find the most suitable ones for the project management's needs. For example, the quadrant diagram shown in Figure 4.6 is a good way to analyse performance of multiple projects in a same graph. However, compared to the time based graphs shown in Figure 4.5, it is not a good representation of the

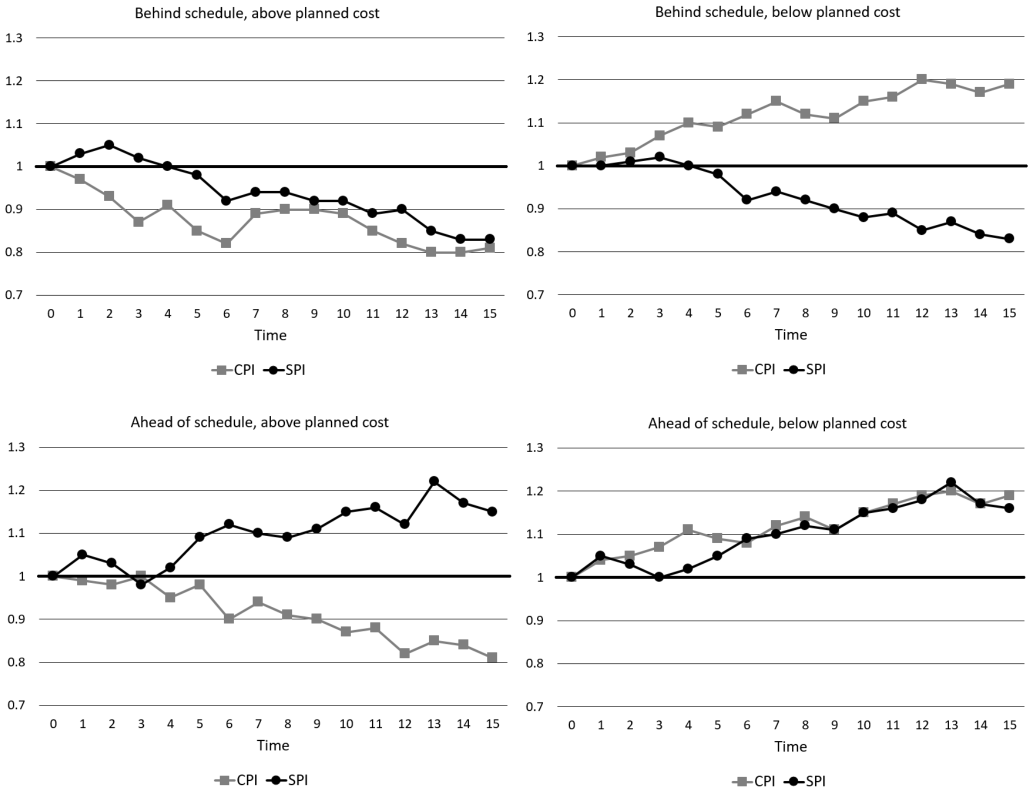

Figure 4.5: Four different project positions indicated by the movement of the CPI and SPI [24].

performance of one project as the ability to visualize the trend in the data is lost.

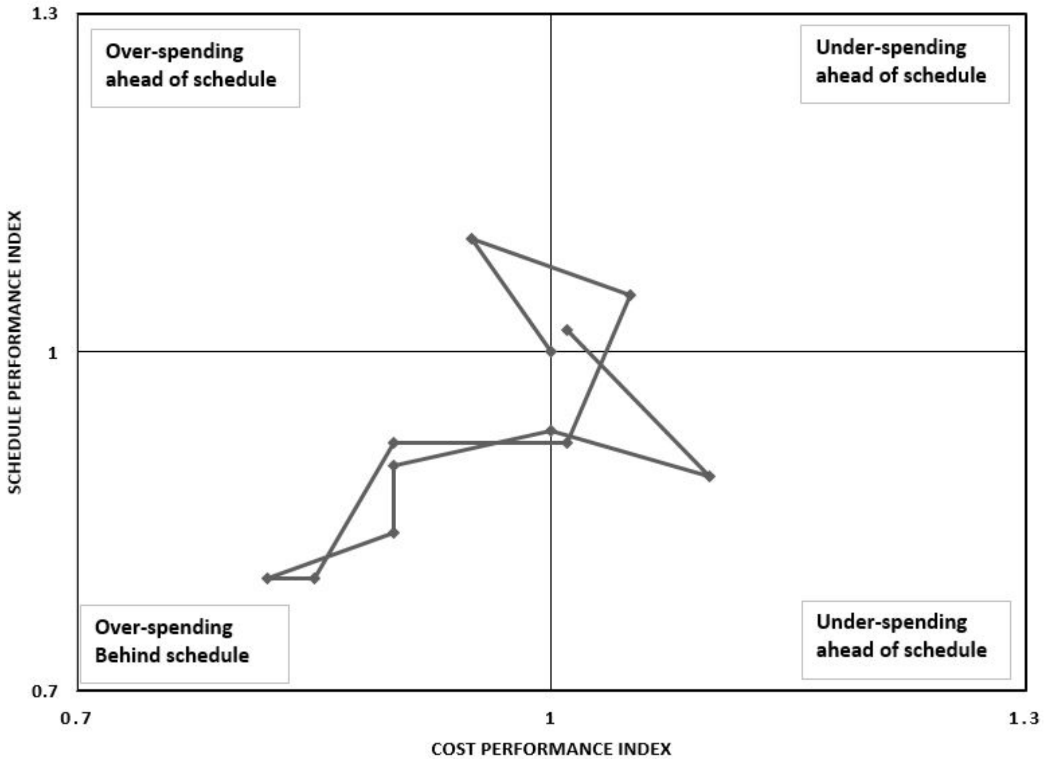

Figure 4.6: Alternative solution to plot the CPI and SPI is to plot them against each other on a quadrant diagram. [24]

4.6 Implementing EVM

"I keep six honest serving-men (They taught me all I knew); Their names are What and Why and When and How and Where and Who."
- Rudyard Kipling

In his poem, Rudyard Kipling sums up the basis of viable project planning in a form of six honest serving men. By enlisting the services of these men any project manager would be well on the way to defining a viable project plan. However, in a case of EVM few more things are needed to be considered and planned. With an understanding of the basic elements of earned value management, the process of implementing one can be discussed.

Earned value management technique is either partly or fully applicable to any capital project among any industry. Factor that also contributes to its implementation is that most of the projects already have much of the basic EVM data available. [24, 28] The ANSI/EIA-748 Standard describes 32 criteria which provide a consistent basis to assist the Government (or a private company) and the contractor in implementing and maintaining acceptable EVM systems. The criteria are divided into five categories which are:

- Organization
- Planning, scheduling and budgeting
- Revisions
- Accounting
- Analysis

All the 32 criteria can be found in Appendix C which also includes Table C.1 that shows how the criteria are divided into these five categories mentioned above. However, this thesis will not review and analyse each criteria, instead the focus is on a broader overall view of the major categories to describe the implementation process in an understandable manner.

4.6.1 Organization

One of the most fundamental criteria for the contractor is to establish a WBS all the way down to a level that describes the tasks that will be performed and their relationship to product deliverables. [29] However, there is no point defining a WBS lower than the basic level at which data is collected by the normal company procedures [21]. WBS is not the only, but probably the best way to specify the effort and to integrate the work scope, the schedule and the budgeted costs [20]. Another critical thing to be established is the organization breakdown structure (OBS) that identifies all the responsible persons for the work effort defined in the WBS. The WBS and OBS are usually been done in a same graph to get the most information out of them. See Figure 4.7 for an example of this.

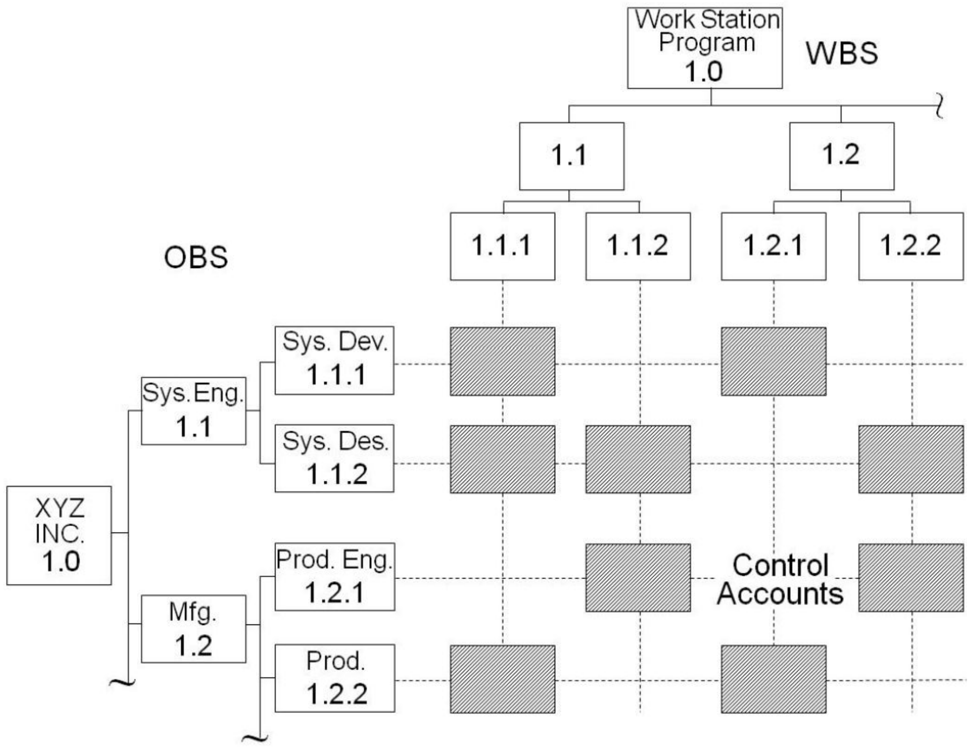

Figure 4.7: Interrelation of WBS and OBS. The intersection of these two establishes the control accounts [29].

The intersection of the WBS and OBS defines the control accounts (CA), a key management control points where the integration of scope, budget and schedule takes place. Furthermore, it is the point where the measurement of performance will occur. A control account plan (CAP) is a plan for all the work and effort to be performed in a CA. It contains a discrete statement of work, a schedule and an authorized budget, and it must be controlled by the control account manager (CAM) for the duration of the project. [18, 20] These CAPs may also include some direct cost items like materials, traveling, subcontracts and even indirect costs [18].

4.6.2 Planning, scheduling and budgeting

An integrated master schedule often helps a project to meet its objectives set in the contract but is also necessary for any project employing EVM. After all the work is defined within the WBS, it must be planned and logically sequenced into a specific time frame. Then resources are added to this schedule in order to determine the budget for the scheduled work. The resource loaded schedule forms the basis for periodical budgets, as well as planned values for each task and thus the whole project. The time-phased budget for the project is now formed and it is also the PMB for the project, against which the project overall performance will be measured when it is being executed. [18, 20, 29] This iterative process of forming the baseline is illustrated in Figure 4.8.

Depending on the resource, its budget may be expressed in any measurable form: monetary, labor hours or some other measurable unit [18]. Planning and budgeting can be done at both the top level and at the detail level. As a consequence, two different methods exist for creating a budget: top-down and bottom-up budgeting. However, according to Fleming et al. [18] a detailed bottom-up budgeting is the preferred method in order for performance measurement to take place during the project execution. The bottom-up method creates a more accurate budget compared to top-down method, because the schedules and budgets are constructed for each individual task in the WBS. These resulting budgets are then aggregated to establish the final budget for the project. Top-down method is more commonly used in project planning as it is easier to construct a complete list of tasks from the top down. Downside is that because the budgets are initially set at a higher level and then broken down into budget estimates all the way down to the lowest level of the WBS, the estimated budgets are not accurate enough for the use of EVM. [30]

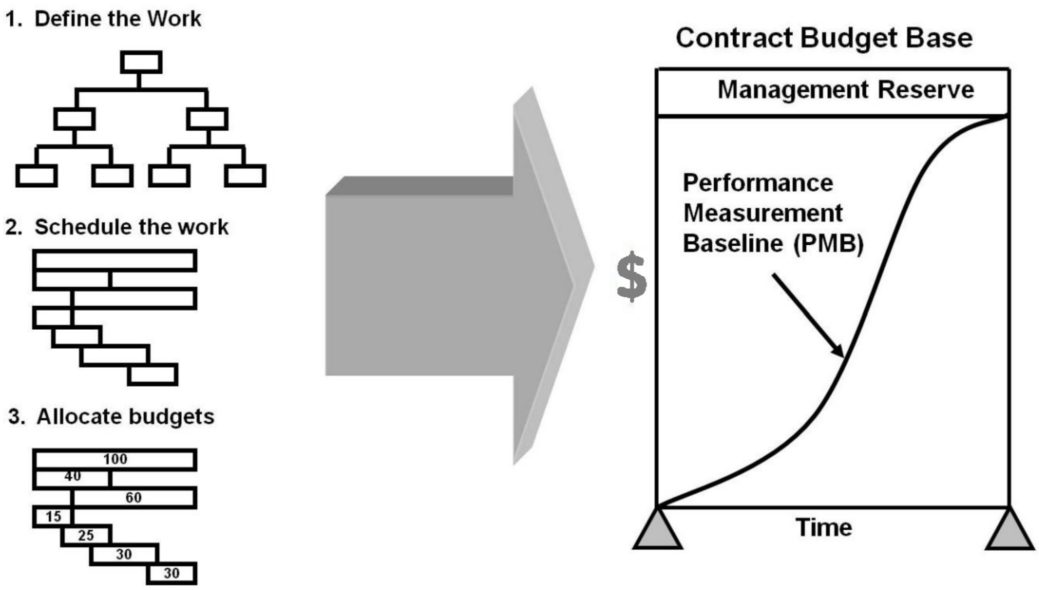

Figure 4.8: Establishing the baseline process. In other words the PMB can actually also be derived from the sum of all the CAPs. [29]

In general, most of the projects may face some unplanned problems that cannot be defined in advance and to cover them the project manager sets aside a portion of the total budget. This management reserve (MR), also called "contingency funds", is in addition to the project's PMB. The sum of the MR and PMB is the total project budgeted value, defined as the contract budget base (CBB). [18]

In any project a successful baseline control demands that all budgets should be logged. This also includes so called undistributed budget (UB), a temporary budgeted value for authorized work not yet negotiated, or future changes, which cannot at present be assigned to any specific CAPs. Anyhow, a viable PBM needs that the UB must be time-phased and allocated to specific WBS elements. [18, 29] Figure 4.9 illustrates one way how all the budget assignments, the WBS and OBS can be expressed in a form of a matrix.

Functional Organizations \ Work Breakdown Structure			Total Project								Organization Budgets
			1.1			1.2			1.3		
			1.1.1	1.1.2	1.1.3	1.2.1	1.2.2	1.2.3	1.3.1	1.3.2	
Top Level Organization	Org. A	Organization A1	1			5			14		20
		Organization A2			12			7		14	33
		Organization A3		4							4
	Org. B	Organization B1				3	12				15
		Organization B2	4		2			3			9
	Org. C	Organization C1	3							1	4
WBS Element Budgets			8	4	14	8	12	10	14	15	85
Undistributed Budget (UB)											5
Performance Measurement Baseline (PMB)											90
Management Reserve (MR)											10
Contract Budget Base (CBB)											100

Figure 4.9: An example of a budget summary matrix [29].

Two additional things that need to be taken into account when planning a project: larger projects may need multiple schedules, with vertical traceability of requirements defined in the project master schedule down to each CAP schedule; on a complex project, some method for example critical path method (CPM) must be used to define the relationships and constraints between one project task to another. [18, 20]

4.6.3 Accounting Considerations

Project costs can be incurred through labor hours, material purchases, equipment deliveries, subcontracts and other direct or indirect costs [13]. In preparation for analysis, actual costs must be collected in a manner that is consistent with the way work is planned and budgeted. This means that actual costs must be correctly applied to the proper work packages within the WBS. The criteria that consider accounting also set high importance to take the appropriate time to schedule an important project resource, material, and to report and accrue costs accurately. [29]

4.6.4 Analysis

Analysis in EVM is basically monitoring the project performance against the baseline for the duration of the project. To do so, project management needs to periodically calculate and analyse variances, indices and other measures that were introduced in Section 4.5. The calculations are usually done in CAPs which provides the ability to aggregate the data all the way up through the WBS and OBS. [18, 29] When analysis of the performance measures is done properly, they can give project management very valuable information where problems are occurring so that extra resources or other corrective actions can be taken in order to overcome these issues. Different graph that support the EVM data analysis were discussed in Subsection 4.5.5.

Estimating percent complete

To ensure accurate and correct EVM analysis, it is important that the EV of a task is estimated correctly. However, estimating the percent complete for a task with any meaningful accuracy is maybe the most difficult task in EVM analysis. [13] This subsection will provide various methods for calculating earned value depending on the type of work being performed. The methods are divided into three categories depending on the type of effort involved with the task.

Discrete effort

Discrete effort tasks are ideal for earned value measurement as they can be scheduled and have a defined measurable end product or end result [18]. Methods to measure discrete effort tasks are described next.

- **Fixed ratio formula method:** The completion of a task is divided in some distribution that adds up to 100%, for example 10/90, 25/75, 40/60 or 50/50 ratio. The first percentage complete is given for the task when it starts and the remainder when its finished. This method is very easy to understand and use, but it also requires detailed and short-span tasks in order to work successfully. [18]

- **Weighted milestone method:** This method works well for planning resources and measuring progress for tasks which have longer duration than two reporting periods. The work package is converted into multiple measurable milestones to reflect finite divisions of work leading to completion of the work package. The total budget of the work package is divided based on a weighted value assigned to each milestone. This method is one of the preferred methods for estimating earned value. However, it requires substantial planning to set meaningful milestones for each task. [18]

- **Percent complete method:** This method allows estimation of the percentage of work completed during each reporting period. These estimates are quite subjective as they are made by the person in charge of a given work package. However, this method is the most desirable when the percent complete can be calculated based on some measurable parameters such as length, square meters, or cubic meters of work accomplished. [18]

- **Percent complete with milestone gates method:** This method combines the best of both weighted milestone and percent complete methods by introducing performance milestone ”gates” that are placed intermittently within long, subjectively measured tasks. The milestones are there to prevent the subjective estimations of work complete to go beyond a given milestone until certain predefined criteria have been set. This is a compromise between the initial planning required with the weighted milestone method and the ease of subjectively estimate a completion percent for work. [18]

- **Equivalent unit method:** This method works well for repetitive work and when the project periods are of an extended duration. Equivalent unit method allows for a given PV to be earned for each full work item completed and also for a fractional equivalent of a full item. [18] For example, a project represents the assembly of ten microcontrollers valued at 100 € per controller. Microcontrollers are assembled simultaneously, which means that when 10% of each microcontroller is done, the measured EV for the full project equals to one completed microcontroller, even though not one controller has been completed.

- **Earned standards:** This method is useful for measuring the earned performance of repetitive work and it is perhaps the most sophisticated method of measuring earned value. This approach is typically limited to repetitive or production-type work. It requires that the equivalent unit standards for the performance of the tasks to be completed are established beforehand. Historical cost data, time and motion studies, setup, teardown, etc., are key elements for the process of measuring performance against earned work standards. However, there is no standard for setting earned value that works best for all types of work, thus often several measurement methods are utilized. The one then employed for individual work packages will be collectively decided within the people who are working on the package. [18]

Apportioned effort

Planning and performance of apportioned effort work has a special relation to another task, a so called base task. The earned value for the apportioned task is assumed to be the same as for the base task. [18]

Level of effort

Level of effort (LOE) is the least recommended method of measuring earned value. LOE represents work that does not have any measurable end product or it is impractical to measure. For example field engineering, coordination, follow-up, project management or other supportive nature activities that are not associated with a defined product are LOE tasks. Because these tasks are more time driven than task driven, they are basically just measuring the passage of time. Since an LOE activity is not itself a work item directly associated with accomplishing the final project product, service or result, but rather one that supports such work, its duration is based on the duration of the discrete work activity it is supporting. Fleming et al. [18] recommend to isolate all LOE effort from a project to their own element in the WBS in order to prevent them from distorting accurate EVM performance measurements. [18]

Earned value with project procurements

Employing earned value on project procurements is more difficult and time consuming than employing it on internal direct labor. Typically, most of the companies have in place some type of a labor reporting system that is quite effective, especially when compared to the way they keep track of the status of their procurements. And like for labor, also procurements need the ability to accurately measure PV, AC and EV to accomplish EVM. Moreover, the tangible performance milestones also necessary for earned value measures often span several accounting periods and are performed by different functions. Employing earned value on procurements, however, is worth the extra effort if the procured items carry high risks, challenging complexities, new technologies and are crucial to the success of the project. [18]

If earned value is decided to be employed on all of the project procurements, Fleming et al. [18] recommend a simple six-step process to accommodate this with the least amount of effort. The steps are:

1. **Continue scope definition to include make-or-buy analysis, then compile a "Listing of Procurements"**

2. **Place all procurements into three generic categories: 1. major, 2. minor and 3. routine.** Major procurements hold high risks and costs but are usually only few in number. Typically, these items will represent creation of something new to project's needs. Minor procurements are typically high value but hold lower delivery risks as they already exist. However, meeting schedule performance of these items is very important. Routine procurements are typically commercial off-the-shelf items or services, and usually high in number. Nevertheless, these articles must be available to support the project schedule, but as they are easily accessible the risks are low. Suggestion is that projects follow Pareto's 80/20 rule [31] when employing EVM to project procurements. Typically, categories 1 and 2 represent 10-20 % of the items to be bought, but perhaps 80-90 % of the total procurement budget.

3. **Determine an earned value method for each procurement.** The different methods were introduced earlier in this section. Suggested methods per category; Major: *weighted milestones, percent complete estimates with milestone gates, schedule of values, or CPM network with resources, full ANSI/EIA-748 flow-down*; Minor: *weighted milestones, percent complete estimates with milestone gates, fixed formula, performance based payments*; Routine: *percent complete estimates, percent complete estimates with milestone gates, apportioned to direct base.*

4. **Time phase a project procurement baseline**

5. **Measure actual earned value performance, estimate actual costs.** If the actual cost data from the suppliers is outdated compared to the internal project data, actual costs for procurements need to be estimated in order to present near-real-time cost performance.

6. **Forecast final costs (EAC) based on earned value performance**

4.6.5 Revisions and data maintenance

Very typical for a project is that the scope of work and the WBS that was well defined in the beginning of the project will not be the same at the end. There are many reasons that can be behind those changes for example a customer directed change, internal re-planning or a change to the scope of work. Regardless what caused the change it is necessary that the changes to the baseline are well documented and controlled. Otherwise, overtime the project's reports would lose their information about the status of the project as they are less and less related to the current scope, schedule and budget. [18, 29, 32]

4.7 Factors that contribute to implementation of EVM

Implementation of EVM is successful if it leads to better outcomes for projects from the cost and schedule point of view. Effective monitoring of the progress and forecasting allows corrective actions to be taken on time which helps the project to stay on track. However, to do so it is not enough to just introduce the methodology into an organization, but instead it must be associated with overall organizational approaches. This includes: [1]

- Colleague-based organizational culture

- Continuing top-level management attention
- Organizational integration mechanisms (e.g. integrated product team IPT)
- Effective training
- Facilitating support system (e.g. accounting, a project management office)

Otherwise the implementation of EVM may be superficial, and therefore part of its potential remains unexploited. In Figure 4.10 is shown effective implementation model for EVM based on research [1]. It uses a broader approach considering four-factor groups which together can remarkably improve the acceptance, utility and performance of EVM in various organizations and projects.

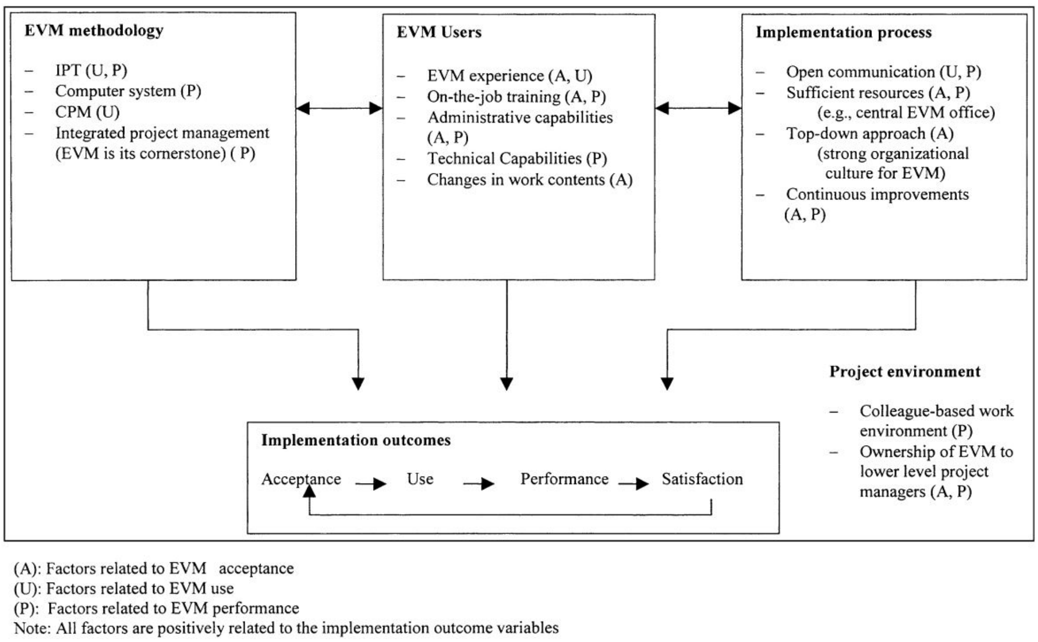

Figure 4.10: EVM implementation model that aims to improve its acceptance, use and performance through four-factor groups [1].

These factor groups are EVM methodology, EVM users, implementation process and project environment. Model shows how each factor contributes to implementation outcomes of EVM via one of these four factor groups.

4.8 Discussion

A project manager is typically the single individual responsible for coordinating a multi-functional team towards the project objectives. To be able to do so, the project manager needs accurate, reliable and timely data to enable effective management decisions. Traditionally, these decisions are based on comparison of planned expenditures against actual costs. However, this approach lacks the most important information of the project status: what work has actually been accomplished.

Earned value management can overcome this shortcoming by including a third dimension into the measurements that is the objective value of work performed, also known as the earned value. This allows a project manager to better estimate the current status of a project and gives an early identification of trends that indicate anticipated project results based on project performance. These early warning signs enable a timely response on the part of project manager to mitigate unfavorable outcomes by taking corrective actions, but also exploit possible favorable opportunities.

In order to work properly, earned value management needs certain prerequisites from the side of organization, planning, scheduling, budgeting, revision control, accounting and analysis. In addition, planned value, actual cost and earned value need to be logged for the duration of the project. However, it is important that the trade off between adequate project status visibility and excessive data collection is recognized and addressed. This can be accomplished by setting an appropriate level of detail in the implementation process that still satisfy all of the project functions. Different factors that affect the level of detail include project size, duration, risk, type of contract, and desired level of management involvement [32]. Adequate level of training and support for different levels of management must also be considered to increase EVM's acceptance, thus utilizing it properly.

Nevertheless, earned value management is a powerful tool for managing projects and also a portfolio of projects [28].

Chapter 5

Implementing EVM in the case company

As projects, project management and EVM are now introduced, it is time to examine how EVM could be implemented in the case company's projects. The research begins with defining a typical project in the case company in terms of scope, costs and schedule, and analysing the current monitoring and control practices. The research is then continued by identifying the key elements of the project. This includes investigation of how these key elements are positioned in the project and what impact they have on it. After that, the research focuses on finding the best way of implementing EVM on the project based on the knowledge of the previous chapters and information about the project discussed in this chapter.

5.1 Characteristics of the projects

In this section a typical project for the case company is discussed. This includes going through general information, investigating WBS and costs as well as planning, scheduling and monitoring practices. Unnamed project/projects with scaled values are used for example purposes.

5.1.1 General information

Following the notion of the PMBOK® Guide [11] definition, a project delivered by the case company is characterized by at least one of the following criteria: [33]

- An activity that is novel and/or ”unique”, as it requires a certain amount of hours of custom engineering effort
- Payments tied to the completion of milestone activities (or % complete) that requires oversight and tracking
- An order that exhibits a significant degree of technical, geographical and/or technical complexity; e.g. project complexity score 200 or higher
- Multiple ABB units are involved and coordination between them is required
- The customer explicitly requires the assignment of a project manager

As a recap from Section 2.2, the case company is a project organization that delivers tailor-made power generation and distribution projects to shipyards. The case company has shipyards located around the world which are seen as the main customers. Thus, the diversity in cultural and practical point of view is high among the customers. In general, projects in shipbuilding industry are extremely time and quality critical. Penalties for late delivery in main equipment and documents are substantial and the equipment must be certified for quality. For example in the case of a cruise vessel, the owner begins to sell cruises for the ship already during the time the vessel is constructed. Thus, every delay in the delivery of the vessel would cost huge amount of money for the owner and give them bad reputation.

The case company has currently multiple projects that are ongoing, most of which are cruise vessels. Minority of the projects are for other vessel types, such as ferries, yachts, tankers and icebreakers. Every year new projects are won and a typical sales price is seven to eight figures in euro.

Typical scope of a project, like the one example shown in Figure 2.1, consists of 10 to 20 main equipment. The case company buys the main equipment as engineered products from different suppliers around the world. Typically a supplier has a basic design ready for the so called "main equipment" which is then tailored to match the project requirements. However, sometimes a totally unique equipment with unique specifications is needed. Thus, the main equipment are usually moderate or high risk procurements in terms of complexity and availability. System level engineering and testing is conducted by the case company. The testing is done in a three-phase process to ensure system level functionality. First, each individual main equipment is tested at the factory (factory acceptance test, FAT), after installation all the systems are tested and finally the operational functionality is tested in a sea trial. The case company adds customer value to the delivered equipment by integrating them into a single system.

The duration of a project typically varies from one year to five years. The duration is dependent inter alia on the shipyard, vessel type, size of the scope, is the vessel first of its kind for the case company etc. The project is considered as started when the contract is formally signed and has entered into force. Usually a bit before or right after that the project is handed over from sales organization to project organization. This is followed by the engineering and design phase. During this time the main equipment are designed and ordered, and the blueprint of the whole system takes its final shape. The project is closed after the case company has fulfilled its contractual obligations. Normally this is when commissioning is finished and the whole system is working without exceptions. If the vessel has been contractually agreed a warranty period, it starts after this project "closeout". Also during the warranty period the responsibility of the vessel is on the electrical systems project organization, however there is a different group of people than the original project team who take care of this process. The life cycle of a typical project is simplified in Figure 5.1. Of course, this model may vary between contracts and it is a very simplified version of the actual life cycle, only including the main activities/processes.

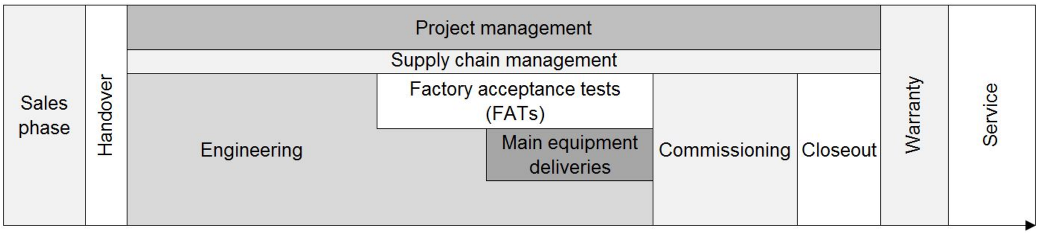

Figure 5.1: A simplified project life cycle model. From the electrical systems project organization point of view, the project is under their control the time from the handover of the project until the vessel is moved from warranty to service.

As a result, a project delivered by the case company is typically a relatively complex and long term endeavour, involving multiple parties as well as various activities and processes.

5.1.2 Current monitoring practices

Due to the long duration of a project typically from one year up to five years, the main monitoring period is a calendar month. Incurred costs are gathered and future cost plans are updated in a monthly basis into the case company's ERP system (Enterprise resource planning system). Allocation of the costs inside the project is based on the work breakdown structure. Although, the ERP system follows automatically labor hours in day precision the hours that were made to the project must be manually filled into the system on the last day of a month at the latest. Thus, due to human habits the last day is usually the day when all the hours are reported. Moreover, as the main monitoring level is a month, it is acceptable but not recommended to report all the project hours of the current month on the last day of the month. Due to these habits, the accuracy of monitoring a project hours in management level is basically a month.

However, some processes and activities have a monitoring accuracy of a week or even a day. This is due to certain characteristics of the process or activity, or even the cost itself. For example: the traveling costs need to be reported in a minute detail due to daily allowances; delivery of a main equipment must be reported to a certain date so that it can be later agreed whether the delivery was on time according to the contract; commissioning is generally followed either in a weekly or even in a daily manner because it is a shorter and more intensive period during a project's life cycle.

The management monitors all the projects in a project review that occurs every month. For this meeting the project manager prepares a "project progress report" for each of his/her projects, and then those are reviewed with the senior management. These files are then stored in a global web system for later usage, such as audition.

Currently project progress monitoring is mainly done using the traditional cost management approach. In other words, the actual costs are compared to the planned costs and then the status of the project is determined based on this comparison. Supportive actions to make this statement are conversations between the different levels of management and possible written reports. Earned value of any activity is not yet being measured. The measurement is a new feature, therefore not utilized. However, some of the ongoing measurements resemble earned value.

5.1.3 Defining work breakdown structure

Currently, the only WBS for any project in the case company is the one that is created in the ERP system. In Figure 5.2 is an illustrated WBS of an example project based on the information of the project in the ERP system. In this illustration some classified information is concealed underneath the "Other" work package and the illustrated WBS is a bit simplified compared to the actual WBS. However, these modifications are minor, thus they do not affect the conclusions made on this WBS.

In its current form, a WBS of the case company's project provides the nec-

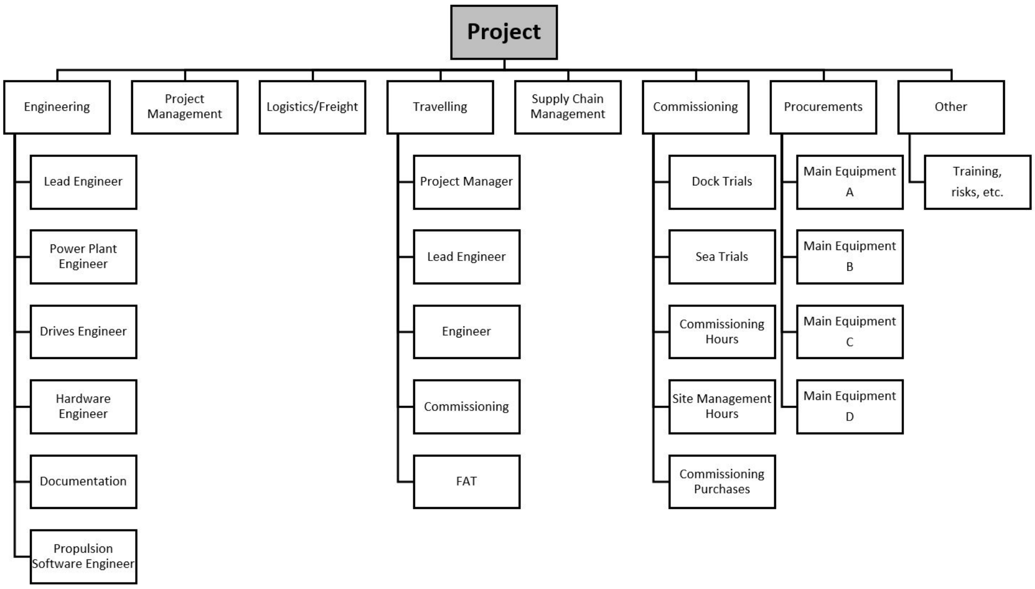

Figure 5.2: The top level work breakdown structure of a typical project of the case company.

essary framework for adequate cost estimating and control. During a project the project manager can easily follow, tune and plan how much money is available, for example, for engineering, but also follow what are the actual incurred engineering costs. Projects are sold using the same structure so it is possible to learn after project completion which costs were underestimated or overestimated already in the sales phase. However, the WBS lacks the second but very important feature of a WBS in definition which is guidance for schedule development and control. As seen from the Figure 5.2, the typical WBS is very high-level and rough decomposition of the project's components. Sequencing those work packages into a practical schedule is basically impossible: project management and engineering happen almost all the time; it is hard to guess precisely when all the traveling will happen; commissioning schedule often specified at a later stage, etc. Moreover, these scheduling difficulties are also reflected to monitoring and controlling possibilities of the work packages over time, which are nearly non-existent.

On the other hand, as the case company is a system integrator more than a manufacturer this WBS in Figure 5.2 is actually close to the reality of what work a project needs for completion. Most of the actual work that creates project progress for the case company and value for the customer is supportive in nature. It may be investigation, problem solving, monitoring, organizing, scheduling, arranging meetings, documenting, defining equipment, etc. These tasks are hard to plan beforehand or give them an accurate budget, thus it is seen inconvenient to include all of them into the WBS.

From a general WBS point of view the main equipment WBS components would be the closest ones to a typical sub-level work packages. However, those are not divided into smaller components because they are ordered from suppliers. Basically, the work related to them on the case company side is defining the equipment, ordering them, following the manufacturing progress, accepting the goods and arranging transport. But then again, these are all those supportive type actions/processes that are related to either engineering, project management or supply chain management, and not directly allocated under the equipment themselves.

5.1.4 Defining cost structure

Procurements are the most dominating package in the cost structure. This can be seen from Figure 5.3 where all the costs of an example project are plotted relatively to the total cost of the project. In this particular example, the procurements are almost 70 percent of the total costs of the project and with commissioning those two form approximately 80 percent of the costs.

However, from the project's progress point of view these two are considered to be around 20-30 percent of the project's progress [34]. The reason behind this is that even though the procurements are high in value they are only the result of all the work, not the work itself. Commissioning, on the other hand is relatively short term process compared to project's life cycle. Furthermore, its success is highly depended on the success of the activities and processes preceding it. Engineering, project management and supply

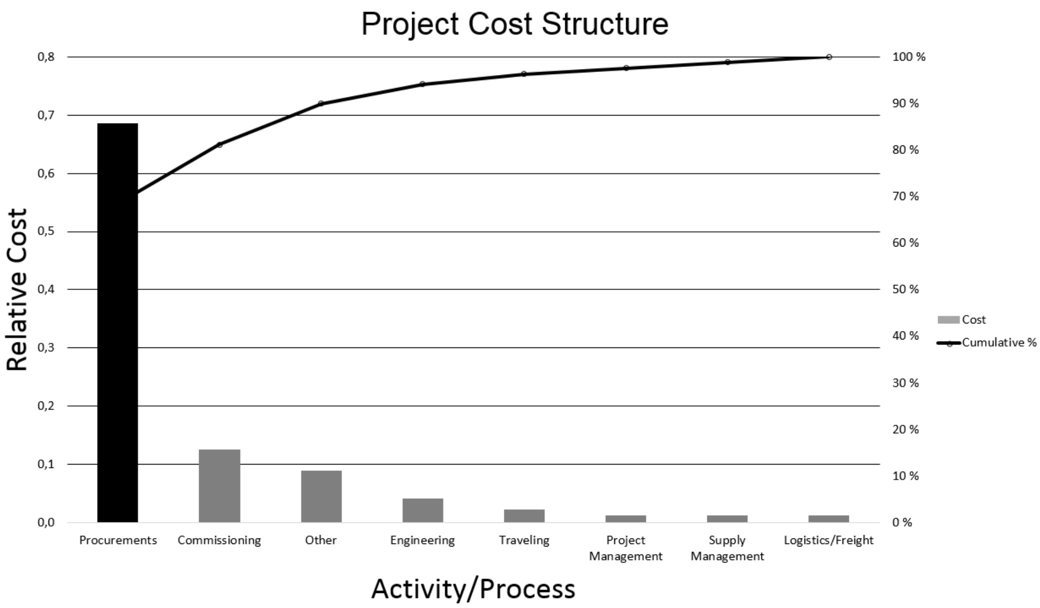

Figure 5.3: Cost structure of an example project delivered by the case company presented in Pareto's chart.

chain management are in monetary value only less than 10 percent of the total budget.

When the cumulative costs associated with example project's activities and processes are plotted on the basis of time a curve close to an "S" shape, like the one shown in Figure 5.4 would result. The shape of the curve is a consequence of the resources committed on the project in different phases. The curve is steepest during the time when the testing and delivering of the main equipment is in progress. This activity causes a peak to both engineers' workload as well as project manager's workload.

Currently almost all the other costs, except procurements are approximated to be incurred linearly during a certain time period when an action that creates the cost is assumed to take place. The duration and timely location of this time period depends on the action/process itself. Costs of the main equipment ("procurements") are usually incurred when the equipment is ready for dispatch at a factory.

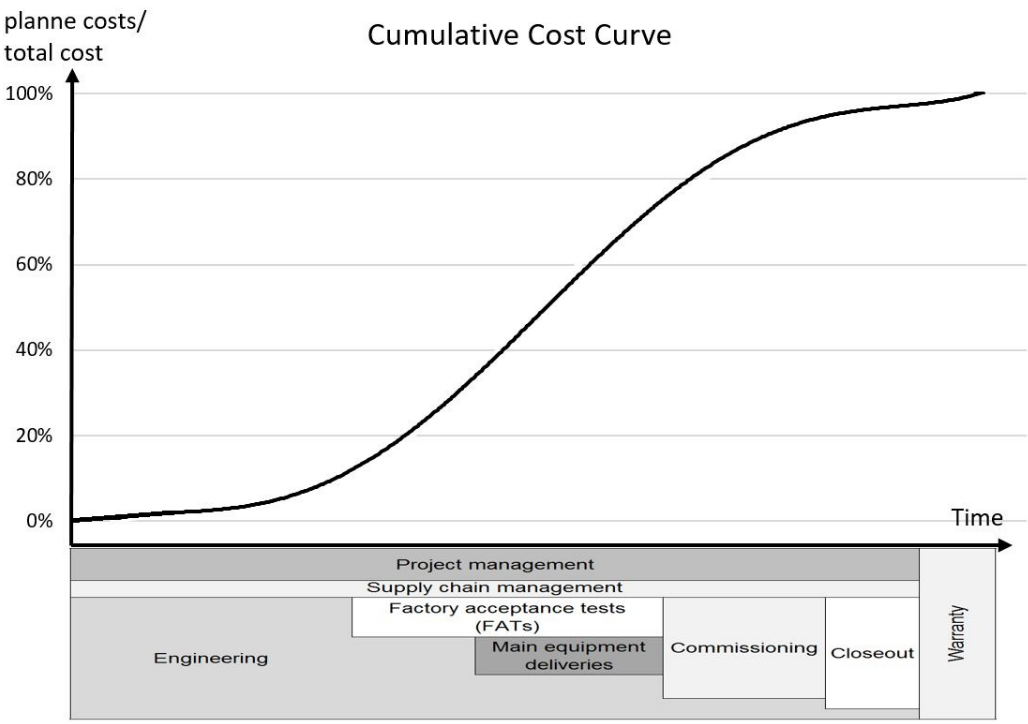

Figure 5.4: Illustrated cumulative costs of a project. They usually form a so called S-curve.

5.1.5 Planning and scheduling

Project main milestone dates are planned and agreed with the customer during the sales phase. Usually these dates consider document and main equipment deliveries and they are related to customer's main manufacturing schedule. All the top level planning and scheduling in the case company is done based on these fixed dates. The critical internal milestones, such as a finishing system design or a dispatch date of the main equipment at the factory are decided based on customer need, lead time and buffer. Any detail level schedules are less commonly created due to unpredictable task patterns and the vast amount of LOE work. Some templates for creating these detailed schedules have existed, however, those found out to be too onerous to be maintained so those are no longer used. In the near future this may chance because the case company has recently invested in hiring planning personnel and new planning software.

The case company uses a sort of bottom-up planning for budgeting, with the help of historical data, experience and expertise. Tag "sort of" in this context means that few of the sub-level budgets are calculated starting from smaller tasks and then aggregated upwards to create the final budget, however that calculation is still not started form the smallest of tasks. Commissioning budget is one example of this. Commissioning of each main equipment is divided into smaller tasks that are first sequenced into a logical schedule for the equipment. Then all these smaller schedules are combined into a one main schedule which is used to calculate the total budget for commissioning. However, like seen from the Figure 5.2 this division of commissioning is not included in the WBS of a project. Budget for procurements is of course calculated by knowing the price per each equipment, but then for example the engineering budget or project management budget is mainly estimated using historical data and experts' opinions. In theory, repeat projects are easier to plan because the same work can be considered to have been made already once. This is only partly true due to the fact that each project is unique even it shares the same characteristics than some other project, as discussed in Section 3.1. Moreover, due to low number of projects, statistical models are not reliable and therefore not used.

It should be noted that planning is not restricted to activity schedules, although they may be the most essential documents required. Additionally the following planning documents are required due to the size and complexity of case company's projects:

- Project Management Execution Plan
- Project Responsibility Matrix
- Project Communication Plan
- Detailed Project Work Plan

- Quality Assurance Plan
- Project Safety Plan
- Risk Management Plan and Opportunity Tracking
- Commercial / Financial Plan

5.1.6 Difficulties

Implementing EVM to the case company's projects is not very straightforward task. The current framework for managing projects is sufficient, as the case company is able to deliver successful projects. However, the framework and all the processes are not thought so thoroughly that they would enable EVM implementation right away.

From the EVM point of view, unfortunate is that most of the critical work which makes progress for the project is actually LOE work. Normally LOE work is leaved outside from the EVM baseline and measurements, as it reflects nothing but the passage of time as discussed in Subsection 4.6.4. However, in this case it is necessary to include it into the baseline due to high value in terms of progress for a project. Implementing EVM on these activities is not impossible, but it just needs a well thought approach to manage them. Is it then converted to percent complete discrete measurements, weighted milestones or something else that best describes the progress.

What makes this even more complicated is the cost structure of a project. Like discussed earlier in this chapter the procurements are the single most dominant element in a project's budget, with portion usually of 60-80 percent of the total costs. Thus, the inefficiency in other elements execution does not have so high direct impact on project's monetary success. However, the indirect link between the less valuable elements and high value elements exists in a way that the success of low value elements is reflected in the success of the high value elements. From this point of view the low value elements can actually have a high cost and profitability impact on the project if they are not done efficiently and effectively.

Like seen from the WBS in Figure 5.2, the budgets for each element are not planned in detail. For this reason the budgets are then revised as the project progresses. Money may be transferred from one element to another where more money is needed. This is not a problem in implementing EVM, but it must be addressed. EVM in its fundamental form requires a proper scheduled budget and resource allocation, which means that the plans must be updated consistently alongside with this kind of changes in the project. Furthermore, adequate revision control is needed to manage all these variations. One way to ease this work would be to revise the WBS so that it would be more detailed and so support more planning, scheduling and also implementation of EVM.

A couple of things make planning of a project in the case company a bit more trickier than one would think in the first place. The case company is very customer-oriented, which on one hand is an advantage but on the other hand it sometimes makes planning and forecasting activities difficult. Processes need to be tuned in the middle of execution to fulfill customer desires, for example the customer wants some specific document earlier than it was planned to be done. Additionally, schedules for some of the later activities, such as commissioning, is agreed to be revised when it is timely. This also leads to the fact that similar items, like documents, may have varying importance from the customer's perspective. This kinds of issues are normal for customer-oriented companies, however, they add their own uncertainty to the planning activities. The question is that how far we are willing to go to satisfy the customer on our own expense?

One thing that rose up in discussions with project managers in the case company was that they have their doubts about the EVM. Some questioned its usefulness and functionality in our projects and others were afraid of the growing workload without getting any benefit from it. Anyhow, this does not mean that implementing EVM should be cancelled based on those assumptions, however they cannot be ignored. Voice of those who would use this method in the future must be heard and they should be engaged in continuous improvement of the final system. In addition, proper training for project managers and full commitment of the management to this new management method could also mitigate this potential resistance.

Due to the high complexity projects and above-mentioned difficulties, it was decided to target this final part of the research to only one element of a project, which I and my instructor together would find out to be the most significant. EVM concept is then implemented on that part of the project. Otherwise, it would require much more research and development to be able to implement EVM on the whole project in a reasonable manner and in given time. In the beginning of the implementation of EVM on part of the project it is good to identify these few predominant elements and try to exclude other not so important ones.

5.1.7 Identifying the key elements in terms of progress

After discussing all the different elements of a typical project in the case company, the most important ones can be identified. Although, every action and process, big or small, expensive or inexpensive, can be thought to be needed to finalize the project, some of them are more critical in terms of project progress and success. From the case company's and customer's point of view the items are: commissioning, project management, supply chain management, procurements and engineering. Next, few details per element are discussed to justify this decision.

Commissioning

Commissioning is the second largest activity in terms of money. However, timely it is not very long period of time compared to project's lifespan. Usually the most intensive commissioning period lasts from one to six months.

Commissioning is important for project success because the stage adds the final value to the equipment by integrating them to one functional system. This is also the last point when everything can be tested before handing it over to the customer. Due to the tailor-made requirement for most of the projects, the expectation is that after commissioning ends the system is working. Currently commissioning is already reported in daily accuracy using different templates. Hours spent with each equipment is recorded and also the type of work so that was it normal commissioning or troubleshooting etc. Written reports are used to give an overview of the progress of the commissioning to other parties involved. Earned value of the commissioning could be calculated as a percentage value using the hour reporting tool in which earned value for every equipment is reported, by either a site manager or commissioning engineer. However, there is not yet any standardized instructions how that earned value per equipment should be evaluated.

The management has already high focus on monitoring and controlling commissioning because if can be very expensive for the project in case there is lots of adversities during its execution.

Project management

Project manager's work is mostly LOE work, on other words supportive. Although, it is not directly related to the completion of the project, it is extremely crucial in achieving project's objectives both efficiently and effectively. Project manager has also lots of responsibilities to take care of: financial responsibility of the project; he/she is the main communication point between the customer, suppliers and internal parties; managing risks and opportunities; arranging required meetings; organizing the project as a whole, etc. The entire project management process is depicted in a form of a flow chart in Figure D.1 in Appendix D. If project manager fails to do his/her tasks properly and on time it will affect other activities/processes and so the whole project. Thus, EVM in some form and extend would be justified in order to see whether the project manager is doing effectively at least all the critical activities. Project manager's work is just very hard to monitor and control using EVM due to the vast amount of LOE work what is also the least desirable method of measuring earned value.

Supply chain management

Supply chain management (SCM) in the case company comprises supplier audits, supplier contract control, making purchases and solving all kinds of issues with the suppliers. From a project point of view, competitive bidding for offers and making the purchase orders are the most important actions. SCM has its most impactful time to a project before the main equipment orders must be send to the suppliers. The suppliers can then officially reserve their manufacturing slots and confirm that they can deliver ordered equipment on time. Although, in the end buying all the equipment for the project relays on SCM's shoulders, they need good co-operation with project management and engineering to be able to do that. SCM can place an order for equipment only when engineering has completed the design for it and project management has confirmed its delivery schedule and other possible contractual obligations related to it. Due to this highly dependent co-operation relation to other processes, it might be practical to include SCM's EVM under these more bigger processes like project management or engineering, using for example a weighted milestone model [18]. After all, following SCM process using some form of EVM would be helpful as it can be a bottleneck for a project progress if things are not done.

Procurements

Procurements are the most valuable elements in a project, which of course make them very critical for the project. However, due to the fact that they are ordered from suppliers there is not much to do to control them except ordering them on schedule and asking for progress reports from the suppliers to ensure on time delivery. Almost all of the actions which are made for the favor of procurements are actually milestones either in project manager's, lead engineer's or supply chain manager's schedule. Thus, procurements are apportioned effort work, which progress is depended on the progress of other tasks. That is why implementing EVM on procurements process could be a bit exaggerated. Focusing on following the on time delivery forecast of the equipment is rational from the case company's point of view as well as customer's point of view. Customer satisfaction and penalties relay greatly on these fixed dates.

Engineering

Engineering is considered to be all the tailor engineering work needed for the equipment and the whole system in order to make it fulfill the contractual obligations. Main responsibility of this work is on a lead engineer, who has few support engineers to help him in various of tasks.

Lead engineer's work includes high diversity of designing tasks, including different analysis, problem solving, calculations, documentation, making reports etc. Lead engineer has to ensure that all the equipment are designed, engineered and manufactured properly so that each of them will individually work properly. Furthermore, each equipment must fulfill the system side requirements in order to work together. Lead engineer has to constantly keep in mind both the system design and equipment design even when working on just one of them.

Engineering can be thought of as being the cornerstone for project's progress and success, because it provides lots of necessary and mandatory information for other project elements to enable their progress. Few examples: SCM can order the main equipment when engineering has provided the technical information; commissioning has much better chance to success if the system engineering has been carried out properly; in the end the customer will see the results of the custom engineering in a form of a fully functional vessel. Engineering progress is therefore very important to be monitored and controlled. EVM in engineering process follow-up could provide important early information if engineering starts to lag behind that otherwise could be seen only when some deadlines are being missed. Furthermore, as engineering is itself a significant entity in case company's project it could be considered to be that also from the EVM point of view so that it is not concluded to any other project process.

5.2 Practical application of EVM

Like discussed in Subsection 5.1.7, after identifying the key elements of a typical case company's project, this research will focus more on finding the best solution to use EVM on one specific key element of the project rather than go briefly through all of them. After different discussions between my instructor Juho Salonen and head of project management Tommi Koskinen, the decision was to take a closer look at the engineering process and how it could be monitored and controlled using EVM.

The main problems are to identify from the engineering process point of view that what should be measured, when it should be measured, how it should be measured and how to interpret these results? The goal is to re-engineer the concept of EVM so that it is not too excessive to be implemented on the engineering process but it would still provide valuable means by which to analyse project's engineering status.

5.2.1 Integrating earned value into engineering process

Engineering is a complicated activity in terms of EVM as it is partly LOE work and partly discrete effort. To make actual progress in engineering, it sometimes requires lots of investigation, simulation and troubleshooting for example, which are not associated directly with accomplishing any product for the project. Moreover, hours used for this kind of activities are not budgeted beforehand, because they cannot be predicted in advance. Whereas discrete effort comes down to various of documents which are the physical items that represent the progression of the engineering work. These documents will finally define all the equipment and the whole system. Furthermore, the most important of them are contractually scheduled as the customer needs them for their own design activities. Thus, from EVM point of view the earned value (EV) in engineering process would be ideal to be related to completion of technical design documents rather than for hours expended. Actual cost (AC) and planned cost (PV), which are the other two key components of

EVM are already logged to case company's ERP system. Table 5.1 aligns the key terms between EVM and engineering process.

Table 5.1: Review of EVM and engineering process terminology.

EARNED VALUE	**ENGINEERING PROCESS**
Planned Value, PV	Budgeted Cost of engineering
Actual Cost, AC	Actual cost of work performed by engineering
Percent complete, PC	Estimated percent complete of contractual documents per document set
Earned Value, EV	Actual cost multiplied by the Percent complete
Performance Measurement Baseline, PMB	Scheduled budget curve

Currently the mandatory engineering documents are listed in a follow-up tool in the beginning of a project. That tool is used for on time delivery, information flow and documentation structure purposes. However, it also has a feature that calculates the percentage of delivered documents compared to total number of documents. Unfortunately, this percentage value is often misleading because it does not follow the engineering PMB in any ways. The current PMB for engineering process is just a line that starts from zero and goes up to the budgeted value during the time period that engineering work is estimated to happen. Whilst the documents follow the contractual delivery dates, thus their completion percentage is more periodical. Moreover, that percentage value of delivered documents often decreases every now and then as more documents are added to the list, which were not yet known to exist at the time the list was originally prepared. Due to the fact that the engineering work itself is not scheduled in an uniform way, it forces to find a modified approach to implement EVM on the engineering process than the general process discussed in Section 4.6. Idea that could be implemented on the current framework is an average earned value concept that is based on efficiency where the value of the work performed is calculated on a certain predefined periods rather than on individual tasks. Otherwise, it would require more research and revising of the engineering process, in other words, figuring out all the engineering tasks and how to schedule them.

To define the periods when engineering efficiency is measured, the needs of both the customer and the case company must be taken into account. The points where desires of the both parties meet are the contractual delivery dates for certain sets of documents. At those points in time (milestones) the engineering has obligations to deliver documents to the customer and the customer can expect to receive them. Without proper scheduling that is the latest point when to start monitoring the engineering process and look for future corrective actions.

The earned value is revised at each milestone by taking account the actual costs and the percentage of delivered documents per achieved milestone. The earned value is calculated by multiplying the actual costs incurred at that point by the average completion percentage of delivered document sets. And when the project proceeds further, on every milestone also the previous percentages are revised if those were not fully completed before or there has been some other reason for change. Completion percentages of every document sets are accumulated forward on every milestone so that the earned value will always take account the historical efficiency of the work performed. This concept is illustrated in Figure 5.5.

In the Figure 5.5 the document sets are drawn as blocks starting from the date when the engineering process (or the whole project) starts. They are therefore parallel because in principle they can be done simultaneously. However, due to limited resources it is often more convenient to do them in sequential way and in prioritized order. Average completion percentage (ACP) represents the average portion of delivered documents of the total documents that contractually should have been delivered at that point in

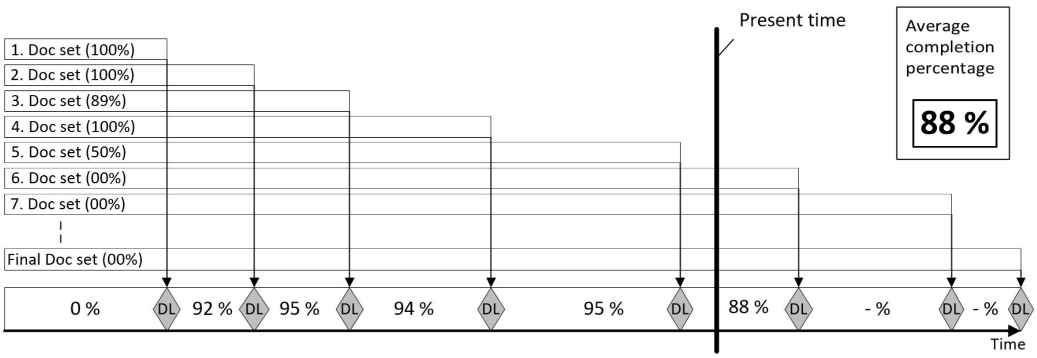

Figure 5.5: Visual representation of how the earned value is formed for the engineering work in an example project. In the figure DL means deadline.

time. This value could be achieved from the current document follow-up tool with a little work. Currently, the document follow-up tool calculates the delivered documents percentage by dividing the number of documents delivered with the total number of documents to be delivered within a project's life cycle. Thus, it cannot be directly used for the purposes of this EVM concept. However, the tool has the planned issue dates as well as the first issue dates for all of the documents. Based on these dates the ACP can be calculated. In this example in Figure 5.5 after passing the fifth milestone the ACP is calculated in the following way:

$$\text{ACP} = \frac{100\% + 100\% + 89\% + 100\% + 50\%}{5} \approx 88\%, \tag{5.1}$$

where the values are from the left: 94% is the completion percentage of the first document set, 100% of the second, 89% of the third, 100% of the fourth and 50% of the fifth. And using this value the earned value at the fifth milestone can be calculated (example values for PV and AC are used):

$$PV_5 \quad = 8000 \tag{5.2}$$

$$AC_5 \quad = 7600 \tag{5.3}$$

$$EV_5 = \frac{AC_5 \cdot ACP_5}{100\%} = \frac{7600 \cdot 88\%}{100\%} = 6688. \tag{5.4}$$

For clarity, if on the sixth milestone all the documents are delivered, including the five previous sets, ACP would go up to 100%. However, the previously logged values on each milestone are not retroactively updated in order not to change the history. An example table how ACP is logged on every milestone is shown in the Figure 5.6. Currently, good place to revise the document

	Deadline 1	Deadline 2	Deadline 3	Deadline 4	Deadline 5	Deadline 6	-	-	-
Doc set 1	92%	94%	100%	100%	100%				
Doc set 2		96%	98%	99%	100%				
Doc set 3			84%	84%	89%				
Doc set 4				95%	100%				
Doc set 5					50%				
Doc set 6									
-									
-									
-									
ACP	**92%**	**95%**	**94%**	**95%**	**88%**				

Figure 5.6: Example table that show how the completion percentages per document set and the ACP of each milestone can be logged.

delivery status would be the monthly held project review meetings and the values could be logged in the monthly prepared project progress report. Logging PV and AC would not change from the current way, and EV is logged in those months where document deliveries happen. It is good to notice that document deliveries may or may not occur every month. And in the case that multiple milestones happen in one month, those all affect to the ACP of delivered documents.

ACP as it is described earlier in this Section is more suitable for the requirements of this earned value concept than the total completion percentage that would be calculated based on all the documents. Because the total completion percentage does not have a planned values that the performance could be measured against, it can only provide information that some progress is happening, but not how effectively it is happening. Moreover, if the earned value would be calculated as multiplication of PV and the total completion percentage, it would be very misleading as the PV itself is not planned in any way according to the document deliveries. Whereas, the ACP focuses more on the most immediate deliveries, also providing information that how well those goals have been achieved. It will therefore better reflect the current situation. Thus, it is more desirable to use in this concept.

5.2.2 Interpretation of the results

After obtaining some results it is important to understand what they mean, and in this case what they tell about the status of the engineering process. By calculating the key metrics of EVM (introduced in Section 4.5) for the example values used in previous Subsection 5.2.1, it is easier to interpret the results.

$$CPI = 0.88 \tag{5.5}$$
$$SPI = 0.84 \tag{5.6}$$
$$CV = -912 \tag{5.7}$$
$$SV = -1312 \tag{5.8}$$

By looking these metrics, it is possible to see that the project is not performing very well from the engineering process point of view. CPI and SPI are less than one which means that both the cost performance and schedule performance of the engineering are ineffective. CV and SV tell the actual monetary value how much the engineering is lacking behind. However, how alarming this status actually is, depends on the set lower and upper control levels. For example, if CPI and SPI are allowed to vary between 0.8 and 1.2 this situation would not cause any actions yet. But at this point it is important to try to find an indication of possible developing trends based on the historical overview of the figures. Good way to do this is using graphs. Example graph in Figure 5.7 shows how the key components of earned value would be drawn as a function of time. The values used in that graph are example values related to the values discussed earlier in this Section.

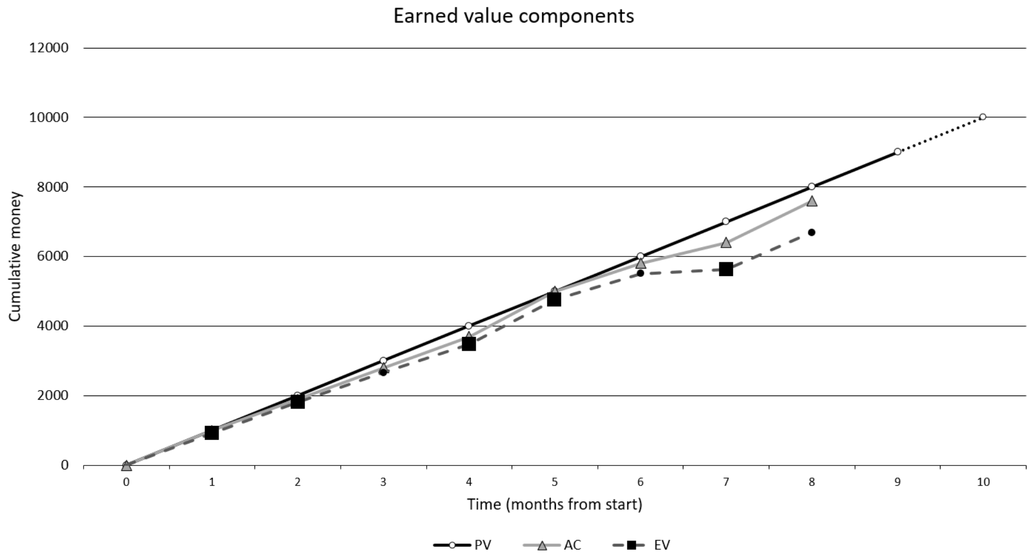

Figure 5.7: The key earned value components with example values.

The black rectangles in Figure 5.8 represent the milestones. In other words, if there has been one or more document set delivery dates during the month it means that the ACP of the delivered document sets is revised, as well as EV. Figure 5.7 is a visual representation of the status of the engineering process of a certain project. However, due to the monetary y-axis values, it is not possible to compare the status of the project to other projects based on this graph. To get an overview of the performance of the engineering process which is also comparable to other projects, CPI and SPI must be used. They are relative values, thus, comparable to same indicators of other projects. CPI and SPI can also be drawn as a function of time as in Figure 5.8.

One more graph could be drawn that contains the EVM variances as a function of time. An example of this is shown in Figure 5.9. It helps to interpret Figure 5.7 by showing the monetary differences between the key earned value components in a better scale. However, CV and SV are mone-

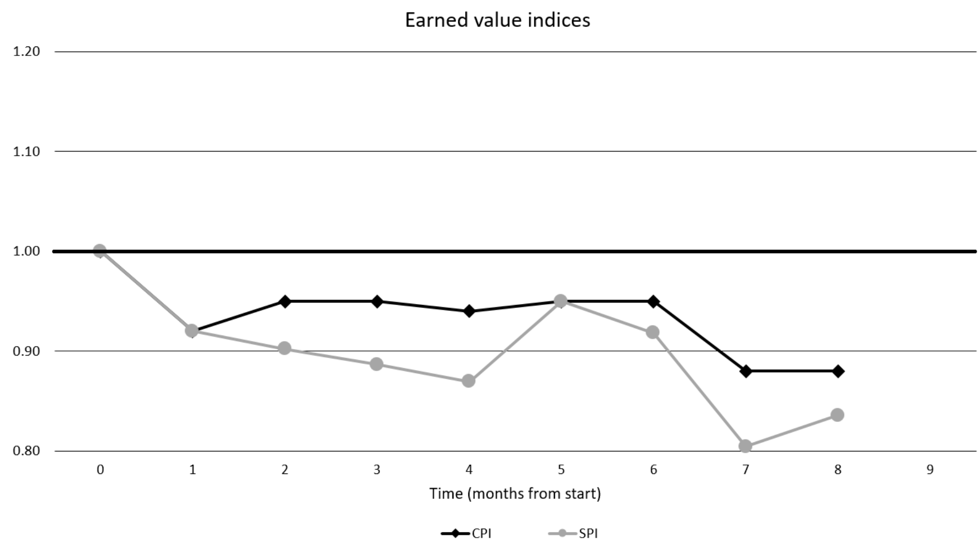

Figure 5.8: Example graph showing earned value indices as a function of time.

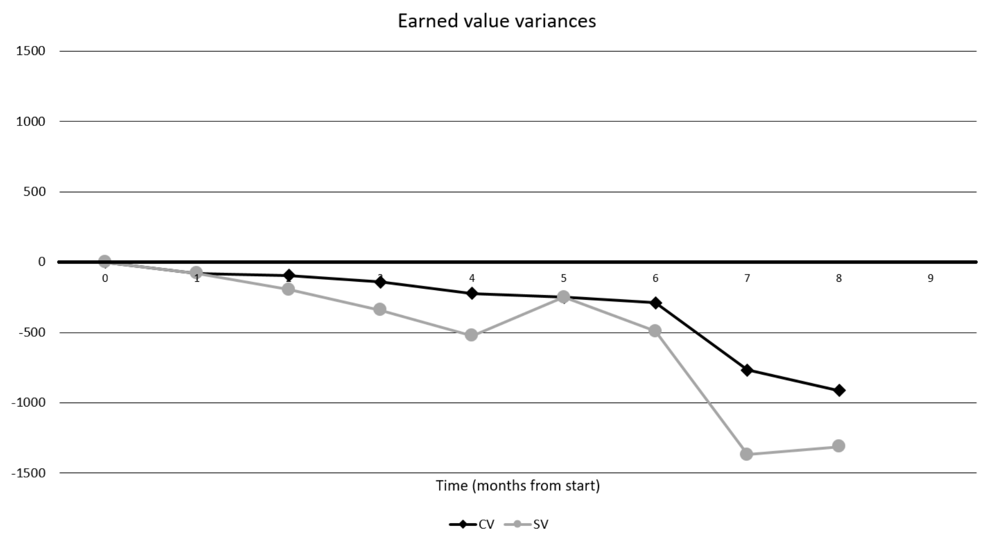

Figure 5.9: Example graph showing earned value variances as a function of time.

tary values and this has to be addressed if comparing these figures between different projects. They show the same information in all the projects, but for example in some smaller project the same figure as in some bigger project can be much more alarming.

5.2.3 Validation of the concept using a real project

After discussing how EVM could be integrated to the engineering process in practice and with example values, it is meaningful to validate the concept using values from a real project. Let us call this project as ”Project A”. The figures of Project A are scaled with random number so they are only indicative values and do not give the order of magnitude, except if compared to each other. Data that is used for drawing the graphs in this subsection can be found from Appendix E.

Project A has been under execution now for 11 months. It is already known that Project A has had major problems in engineering process due to high workload, fresh lead engineer and lack of supportive resources. Some of the problems have been resolved and schedule has almost been caught up, however, there is still room for improvement in performance. Therefore, it is now interesting to see how well the earned value concept will actually reflect this already known status and what it can tell about the future.

Figure 5.10 shows an overview of the engineering process status of Project A. As can be seen from this figure, cumulative AC increases with a steeper slope factor than cumulative PV and also has exceeded it after seven months. If the curve will stay like this, it is obvious that final actual costs will shoot over the budget. But how much, it depends how EAC is calculated: using the current slope factor or one of the equations introduced in Table B.1. Three example values for EAC are calculated in the end of this subsection. What makes the status even more alarming is that EV is still lower than the actual costs. This means that even the planned costs are exceeded, the work that should have been completed is not completed. In other words, the customer has not received all the documents that should have been delivered to them by execution week 11 and engineering is lacking behind from the schedule.

Moreover, a clear decrease is visible on the cumulative EV curve at the last two measurement points (ten and eleven), whereas the actual costs have been increasing steadily. This indicates that even the engineers are doing work as before, part of the most critical work (customer deliveries) is not

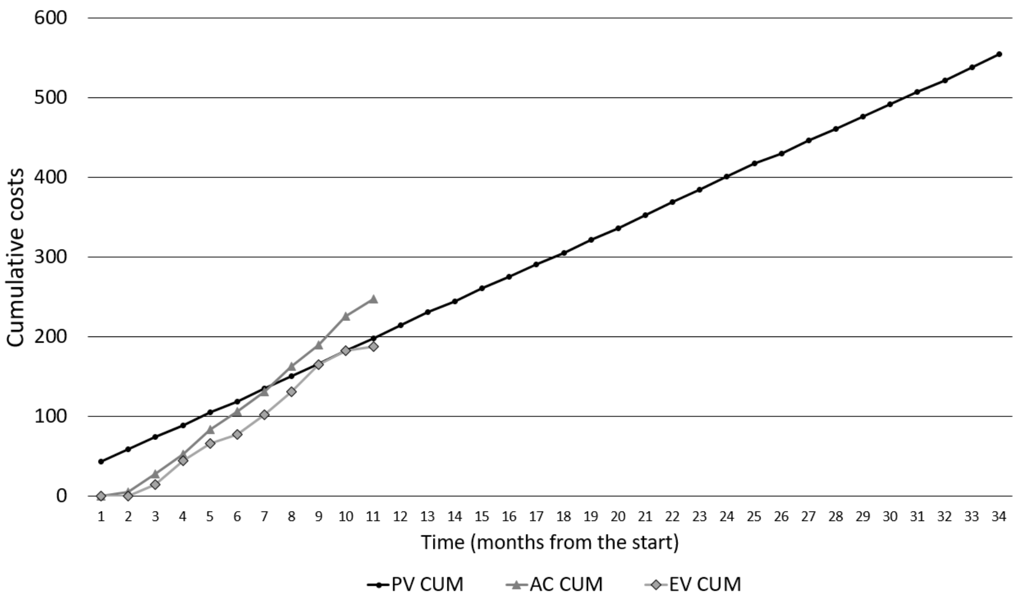

Figure 5.10: The key components of EVM from the engineering process of Project A. PV and AC are achieved from the case company's ERP system and EV is calculated as is described earlier in Subsection 5.2.1.

completed on time. There is either too much other work to do in the project, work is done ineffectively, contractual delivery times are too tight or the phenomenon is the combined effect of these issues. Anyhow, some corrective actions should be immediate in order to avoid the future cost overrun of the engineering process. About one-third of the life of Project A has now passed, thus there is still time to get the project back on track. The gap between AC and EV must be caught up, and the monthly costs incurred must be deducted or the total budget must be increased. Customer claims are also possible additional costs that may result from this ineffectiveness, but they are not shown in this graph.

CPI and SPI of Project A are shown in Figure 5.11. CPI varies close to 0.8, which indicates the same issues in the performance of the engineering process of Project A as was discussed above. Approximately 20 % of compulsory work is not finished at the milestones. On the contrary, by looking

SPI the project is almost on schedule as it is just below 1. However, this is not true based on the already known status of Project A and on the interpretations made from Figure 5.10. Although the developing trend in the SPI curve has been in the better direction.

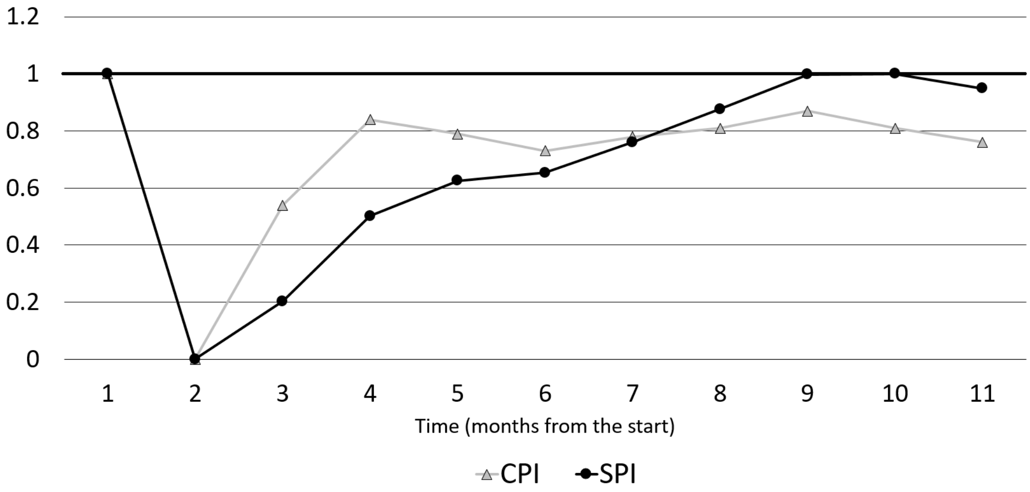

Figure 5.11: CPI and SPI of the engineering process of Project A. The figures are based on the cumulative PV, AC and EV shown in the Figure 5.10.

The reason for this misleading behavior of SPI is clear and it is related to planning. Because PV does not depict the actual work load of the engineering process nor can SPI indicate schedule performance as it is calculated using PV (see Subsection 4.5.2). Thus, the SPI as defined in the EVM does not mean the same in this particular concept. In this concept it shows that how close the earned value is to the planned value at milestone, but because the planned value is not directly related to physical work items this comparison is practically nonsense. Therefore, its use in this concept can be questionable. Updating planned value according to the physical work would solve this problem or at least ease it. However, the current ERP system where the planned value is logged does not allow planning it in such detail that it would help in this issue.

Few example cost estimates at completion (EAC) can be calculated for the engineering process of Project A based on the historical performance and current status. These can give an idea where the project might be going, but how well they can predict the future depends very much of the project team itself and their actions.

$$\begin{aligned}
&\text{Original estimate:} && EAC \approx 555 && && (5.9)\\
&\text{Using slope factor:} && EAC_1 \approx 910 && (+64\%) && (5.10)\\
&\text{Using current cost variance:} && EAC_2 \approx 605 && (+9\%) && (5.11)\\
&\text{Using current cost performance:} && EAC_3 \approx 730 && (+32\%). && (5.12)
\end{aligned}$$

Drawing a graph of variances does not make sense in this example because the values are scaled and the same information can be obtained from Figure 5.10. CV would only show the scaled difference between EV and AC, and SV between EV and PV. And like in the case of SPI, neither SV gives any practical information.

5.3 Discussion

Based on the results in previous Section 5.2, it is seems quite obvious that EVM in its full potential cannot currently be implemented in the engineering process of the case company's project. Difficulties discussed in Section 5.1.6 must first be revised and the remarks in the practical implementation have to be addressed.

Main reason behind the difficulties in implementing EVM to the engineering process is that both actual costs and planned values are related to working hours, not to physical items. In the concept discussed in Section 5.2 the physical items are the contractual design documents. And for EVM to work well it is critical that money and physical work depict each other. Current situation led to EVM concept where earned value is calculated based on efficiency how well the contractual documents have been delivered on time. In its fundamental form of EVM, this calculation should go the other way around so that first monetary earned value is determined based on completed physical work and then efficiency is calculated based on that value. Because earned value in this concept is calculated base on efficiency, one interesting notice can be made. By comparing the ACP and the CPI of a milestone, it can be noted that they are actually the same number. This can also be proven by the following formula:

$$CPI = \frac{EV}{AC} = \frac{AC * ACP}{AC} = ACP. \tag{5.13}$$

This is why a question arises that is EVM even needed if this ACP could provide the same information as CPI which in this case found out to be the most informative and helpful indicator? The answer depends on what the case company wants from the future. One decision is to start following ACP (or CPI) like in Figure 5.11 and ignore other features of EVM. This implementation is straightforward as the framework for doing so already exists. However, it does not provide further development opportunities. The other choice is to develop current planning, scheduling, management etc. actions so that EVM with its needs is there in the background. This way it would be possible to improve and utilize more EVM's features in the future. Then there would be also a certain direction in which to develop and possibility for continuous improvement. In next Subsection 5.3.1 is provided few possible future actions to continue with this second choice.

CPI of the EVM concept discussed in the previous Section 5.2 has one weakness: it can not go bigger than one. This is explained in the way that AC, EV and ACP are determined. Because ACP takes only account the work that should have been done and not any future work, the maximum value for it is 100%. Thus, as EV is calculated using AC and ACP it is at the best the same as AC. And so if EV is equal to AC, the value of CPI is one. However, when this feature is remembered it does not hinder CPI's operation. When a project is progressing flawlessly, CPI should be equal to one. And how much money the project has spent to achieve that status can be seen from a figure similar to Figure 5.10.

The data of Project A that was used to draw the graphs and calculate the EVM figures in Subsection 5.2.3 was best of its kind that could be found from all of the ongoing projects of the case company. The lead engineer of Project A kept it up to date on monthly basis with document controller. On the contrary, in another project that was planned to be used in this thesis, similar follow-up tool was found but it was not updated for a long time, so is was not possible to be used. Moreover, it only had few dates and few documents filled in, thus it was not sensible to use that project as a practical example. It just pointed out the fact that there is a need for harmonization between projects how the document follow-up tool is used and filled in to get the needed information out of each project.

Although, some of project activities may be traditionally considered to be unmeasurable, like project engineering or project management, maybe those processes should be reconsidered so that they could be represented in such a way that measuring them is possible. Like valued "business thinker" Peter Drucker once has said:

"You can't manage what you can't measure."

5.3.1 Possible future actions

Currently, the document sets are planned roughly as can be seen from Figure 5.5. When in reality each document set consists of several documents that could be identified and scheduled, at least in theory. Figure 5.12 shows a more detailed versions of two documents sets and how they are scheduled. This way it would be possible to address problems even before any contractual deadlines are missed. Furthermore, accuracy of the EV would increase and PV curve that follows the document deliveries could be determined. And when PV follows the same physical work as EV is measuring, the EVM indicators that are related to PV, such as SPI and SV would become relevant.

Difficulty with this more detail version of EVM is that the documents are not equally important, which must be taken into account when calculating ACP and elevating its method error. Otherwise, this method will actually distort the estimate of actual work completed per document set. By empha-

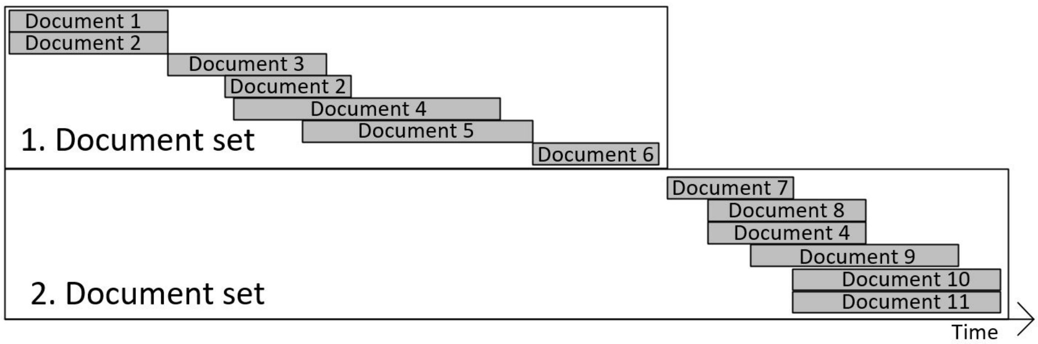

Figure 5.12: How each document set could be scheduled in more detail. Completion progress of a single document could be estimated using milestone model: 0% not started, 50% working on it, 100% completed.

sizing the documents, for example through the importance and the workload, this error can be minimized.

However, there is always the trade off between sufficient planning and excessive planning. And if the more accurate plan is done badly, it may be more of a nuisance than a helpful tool.

Chapter 6

Conclusions

This thesis started with an overview of projects and project management in general. This knowledge was used in the research part to help identifying the unique characteristics and project management requirements of case company's projects. A comprehensive literature review of earned value management was conducted in order to be able to implement it in the electrical system part of case company's project. In the analysis part of this thesis it was decided to focus on implementing EVM in the engineering process of a project rather than in the whole project. The reason behind this decision was the finding when a typical case company's project was defined, that it would require much more research and development to implement EVM concept on a whole project in a reasonable manner than would be possible within this thesis.

The first objective of this thesis was to identify possible constraints and difficulties in the case company's projects which hinder EVM's implementation on them. This was answered in the research part by defining a typical case company's project and discussing about that which characteristics in it would support and which complicate the implementation of EVM. It was found out that both characteristics exist. And it was found out that the project would benefit of using EVM in its management and there are already some reporting practices which are similar to EVM. Due to the complexity of the implementation of EVM into the project, it was decided to be divided into smaller entities and focus on one of them. Project's key elements that would be the most beneficial for the project to be managed using EVM were identified and discussed. Engineering process was taken under closer look and EVM was implemented on it. However, it was also found out the current way of planning, scheduling and monitoring projects is not explicit enough from the EVM point of view. These difficulties were addressed and a concept of EVM was introduced, which was modified based on the limitations of the project.

The second objective was to discover what benefits EVM could provide in case company's project in terms of monitoring. In Section 5.2 engineering process was analysed and a concept of EVM was implemented on it. Implementation started by integrating earned value into engineering process. We found out what should be measured using earned value, how it should be measured and when it should be measured. The developed concept of EVM was first introduced and discussed using indicative example values and finally tested using figures from a real case company's project. It was found out that EVM in its full potential was not yet possible to be implemented into the engineering process. However, this lighter concept already provided a overview of the engineering process performance and ability to compare different projects to each other. Furthermore, it was noted that EVM not only provides already a good way of monitoring this long-term engineering process, but also a certain direction to which the monitoring practices can be developed further. Also problems in the introduced concept were addressed and future actions provided.

Successfulness of EVM in managing a project is often difficult to be validated until the method has been used there for a while. Earned value (EV), one of the key components of EVM is not available in most of the cases, as it is not financially relevant data. So like in this thesis, a veritable estimate was conducted but after a while when the amount of data increases (including EV) the concept can be tuned to a better direction and fix possible problems that come up in it.

Introducing the EVM concept in every project in the case company requires more time and effort than investments. It does not necessarily require any additional software or equipment to be bought, but it just changes a little the way the work is done and measured. The most laborious period is the beginning when every project team must get the same instructions and procedures, in order to make the process consistent between different projects. Nevertheless, time and effort can be eventually converted to money which can be thought to be the initial investment on implementation of EVM. And no company makes investments without knowing that it will payback itself. In the case of EVM this payback consists of successful savings and avoiding cost overruns. Indirect savings can be thought to be the avoided claims and fines which may have been obtained if, for example, some deliveries were late.

The research questions which were introduced in Section 1.1 were answered and the goals of the thesis were achieved. However, the effects of applying the earned value management to the engineering process of case company's project were based on current state analysis and available data. In order to confirm the actual outcome, the engineering process performance must be continuously measured on multiple projects using the EVM concept introduced in this thesis. The final evaluation can be stated in the future based on the usefulness of the data the concept provides and user satisfaction. Also the cost forecasts that were made in this thesis in the end of Subsection 5.2.3 can be evaluated when Project A is finally closed. In conclusion, to summarize EVM and its features from the case company's point of view a SWOT analysis (strengths, weaknesses, opportunities, threats) was carried out. Different internal and external factors identified in this thesis that either contribute or hamper the implementation of EVM were grouped in this analysis. The result can be seen in Figure 6.1. The purpose of this analysis is to give the reader an overview of meaningful factors of EVM in the context of the case company and help to evaluate whether the benefits can be considered to be greater than the potential risks of the investment.

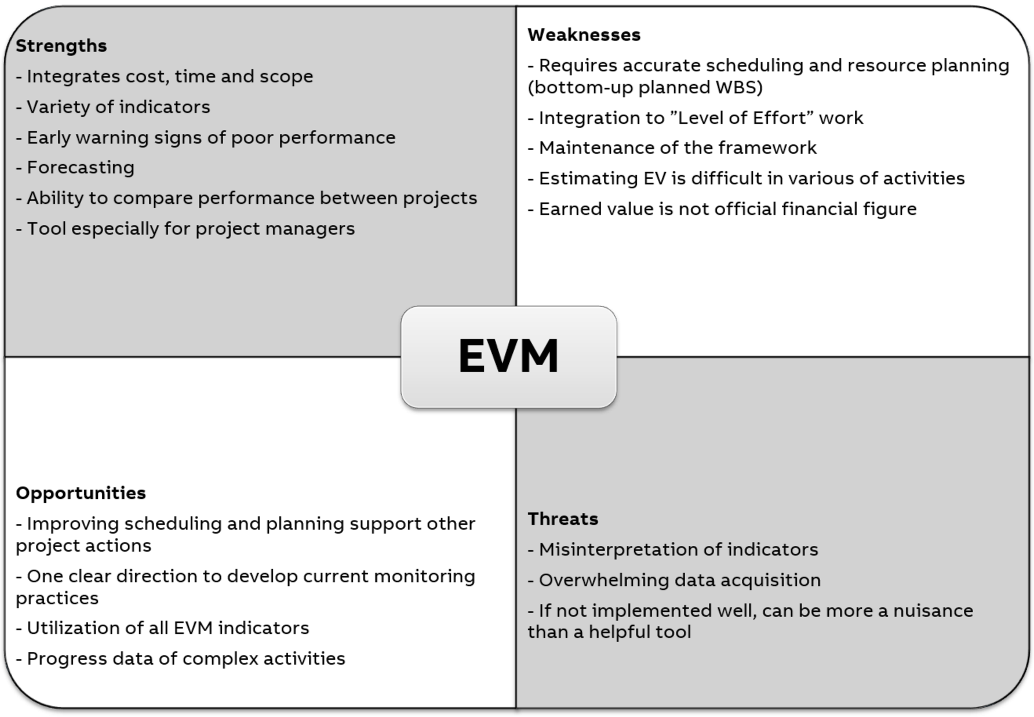

Figure 6.1: A SWOT analysis of EVM in a 2x2 matrix.

After all, ABB Marine is a very successful organization business wise and their products and systems are competitive and have been market leaders for decades. It puts the need of change into question. The continuous strive for improving operations is however what characterizes a world-class competitive company. The results in this master's thesis are suggestions on how to implement EVM into the engineering process and to provide a basis for further internal discussions on what could be done in practice. Challenges and areas of improvements from the EVM point of view were identified. If desired they could now be further investigated and studied in a separate master's theses.

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Appendix A

EVM acronyms

Table A.1: Comparison of Earned Value Management acronyms [19].

ANSI/EIA-748 Standard	DoD C/SCSC Standard
Planned Value, PV	Budgeted Cost of Work Scheduled, BCWS
Actual Cost, AC	Actual Cost of Work Performed, ACWP
Earned Value, EV	Budgeted Cost of Work Performed, BCWP
Cost Performance Index, CPI	Cost Performance Index, CPI
Schedule Performance Index, SPI	Schedule Performance Index, SPI
Cost Variance	Cost Variance
Schedule Variance	Schedule Variance

Appendix B

Other useful EVM measurements

Table B.1: Other EVM metrics.

Metric	**Equation**	**Description**
Cost Variance Percentage (CVP)	$CVP = \frac{CV}{EV}$	CVP is a measure of budgetary conformance of actual cost of work accomplished. $CVP < 0$ the project is over budget, $CVP > 0$ the project is under budget and $CVP = 0$ the project is on budget. [3]
Schedule Variance Percentage (SVP)	$SVP = \frac{SV}{PV}$	SVP is a measure of the conformance of actual progress to the schedule. $SVP < 0$ the project is behind schedule, $CVP > 0$ the project is ahead schedule and $SVP = 0$ the project is on schedule. [3]

Critical Ratio (CR)	$CR = CPI \cdot SPI$	CR, also called the cost-schedule index is an indicator of the overall project health. [3]
Percent Complete (PC)	$PC = \frac{EV}{BAC}$	PC is the percentage of the entire project readiness. [13]
Percent Spent (PS)	$PS = \frac{AC}{BAC}$	PS is the percentage of budget that has been spent. [13]
Cost Estimate to Complete (ETC)	$ETC = \frac{BAC-EV}{CPI}$	ETC is equal to unearned or remaining value normalized to the historical CPI. [19]
Cost Estimate at Completion (EAC)	EAC=AC+ETC $EAC = \frac{BAC}{CPI}$ EAC=BAC-CV	EAC is a new estimate of funds needed to complete the project. The PMBOK Guide provides three ways to calculate EAC. Which one of them is used depends on an assumption that is the past performance of the project a good predictor of the future performance or not. Anbari [3] presents that also other assumptions can be made about future performance and they may result in different EACs.
To Complete Performance Index for budgeted cost (TCPI)	$TCPI = \frac{BAC-EV}{BAC-AC}$	TCPI for cost is an estimate that gives indication of how much effort will be required to get the project back on track and how likely that is to happen. [13]

To Complete Performance Index for schedule (TCPI)	$TCPI = \frac{BAC-EV}{BAC-PV}$ $TCPI = \frac{BAC-EV}{EAC-PV}$	TCPI for schedule is an estimate that gives indication of the level of schedule performance required to finish on time from the report date. [21]
Variance at Completion	*VAC=BAC-EAC*	VAC is the difference between the original budget and the new estimate for a project. [13]

Appendix C

ANSI/EIA-748 EVMS Criteria

The criteria are: [35]

1. Define authorized work
2. Identify Program Organization Structure
3. Company integration of EVMS subsystems with Work Breakdown Structure (WBS)
4. Identify organization/function for overhead
5. Integrate WBS and Organization Breakdown Structure (OBS), create control accounts
6. Sequential scheduling of work
7. Identify interim measures of progress, i.e. milestones, products, etc.
8. Establish time-phased budget
9. Identify significant cost elements within authorized budgets
10. Identify discrete work packages
11. All work package budgets and planning packages sum to control acct
12. Identify and control LOE budgets
13. Establish overhead budgets by organization element

14. Identify management reserve and undistributed budget
15. Reconcile program target cost goal with sum of all internal budgets
16. Record direct costs from accounting system
17. Summarize direct costs into WBS without allocation
18. Summarize direct costs into OBS without allocation
19. Record indirect costs
20. Identify unit costs, equivalent units costs or lot costs
21. Accurate material cost accumulation by control accounts; EV measurement at right time; full accountability of material
22. Control account monthly summary, identification of Cost Variance (CV) and Schedule Variance (SV)
23. Explain significant variances
24. Identify and explain indirect cost variances
25. Summarize data elements and variances thru WBS/OBS for mgmt.
26. Implement management actions as result of EVM analysis
27. Revise EAC based on performance data; calculate VAC
28. Incorporate authorized changes in timely manner
29. Reconcile budgets with prior budgets
30. Control retroactive changes
31. Prevent all but authorized budget changes
32. Document changes to Performance Measurement Baseline (PMB)

ANSI/EIA-748 EVMS Intent Guide [35] defines in detail the management value and intent for each of the 32 criteria listed above.

Table C.1: Earned value management 32 criteria structured in five categories [19, 36].

Category	General Content and Description	Criteria Numbers
Organization	Define the work breakdown structure (WBS), the program organizational structure and show integration with the host organization for schedule and cost control.	1-5
Planning, scheduling and budgeting	Identify the products, schedule the work according to work packages and apply a time-phased budget to them and project itself. Identify and control direct costs, overhead and time, and material items.	6-15
Accounting considerations	Record all direct and indirect costs according to the WBS and CAPs. Provide data necessary to support earned value reporting and management.	16-21
Analysis and management reports	Provide analysis and reports appropriate to the project.	22-27
Revisions and data maintenance	Identify and manage changes, updating current scope, schedule and budgets after changes are approved.	28-32

Appendix D

Project Management Process

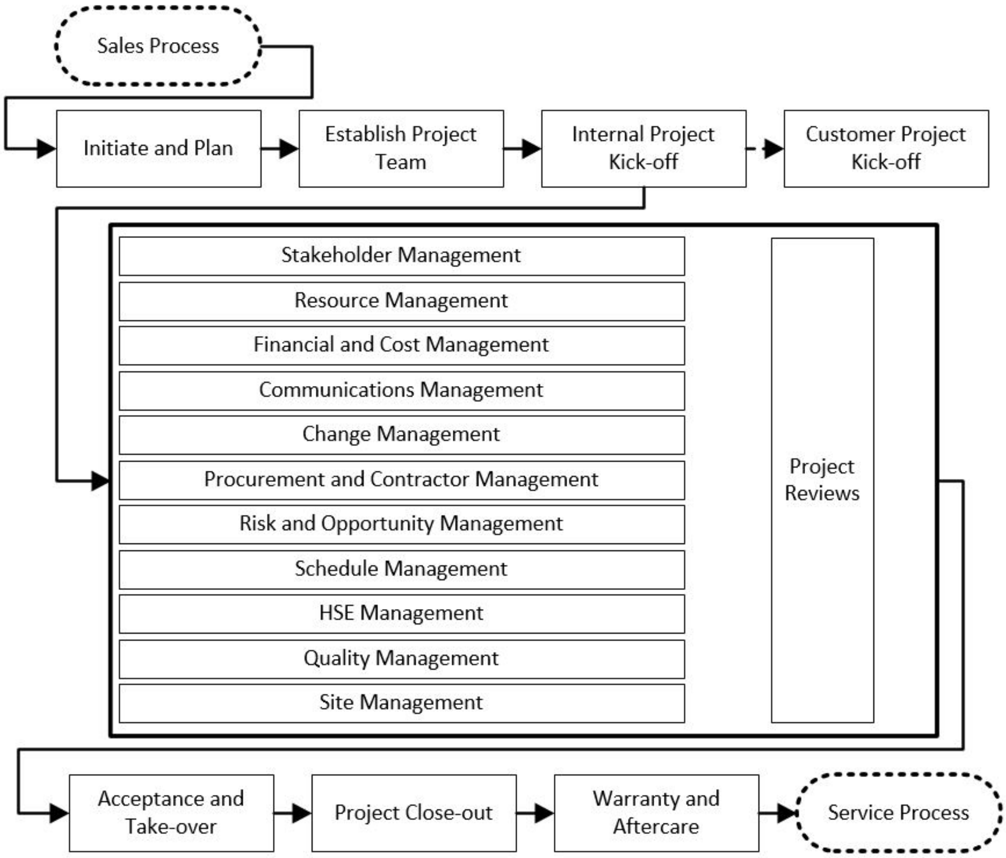

Figure D.1: Project management process flow chart [33].

Appendix E

Documents follow-up data of Project A

See the following page.

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Document set 33	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%						4
Document set 34	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%					2
Document set 35	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%				1
Document set 36	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%			2
Document set 37	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		3
Document set 38	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1

Figure E.1: Document on time delivery data that is gathered from the current document follow-up tool of Project A.